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PROCEEDINGS.

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1927.

THE PHYSICAL SOCIETY

1927-28.

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Authors offering original contributions for publication in the Proceedings should observe the following directions :—

Manuscript.—In drafting the Paper a clear and concise style should be adopted. The high cost of printing calls for the utmost brevity consistent with effective presentation of the original subject-matter.

The Paper should be easily legible (preferably typewritten) and well spaced. It should receive a careful final revision, since alterations are costly when the proof has once been set up.

Mathematics.—Set out clearly, avoiding complex or unusual notations. Wherever possible express fractions in the form a/b (not $\frac{a}{b}$) ; and write decimals in the form 0·123 (not ·123).

Drawings and Tables.—Diagrams must be on white paper or cardboard, in Indian ink, of size sufficient to allow of reduction. Lettering and numbering should be *in pencil,* to allow of printing in a uniform style. The number of diagrams should be kept down to the minimum. Data should be presented in the form of either curves or Tables, but not both.

Footlines descriptive of figures, and headlines indicative of contents of Tables, should be supplied.

Abstracts.—MSS. must be accompanied by a brief abstract, sufficient, however, to indicate the scope of the Paper and to record all novel results.

Proofs.—Proofs of accepted Papers will be forwarded to Authors, and should be returned promptly with errors corrected, but additions or other deviations from the MS. should be avoided.

Reprints.—The Author of a Paper printed in the Proceedings will receive 50 copies gratis, and may receive extra copies at cost price if he so desires.

Contributions by Non-Fellows.—Papers by Authors who are not Fellows should be communicated to the Society through a Fellow.

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PROCEEDINGS
AT THE
MEETINGS OF THE PHYSICAL SOCIETY.
SESSION 1926-1927.

The meetings were held at the Imperial College of Science, the President being in the Chair except where a statement to the contrary occurs.

October 22, 1926.

A DEMONSTRATION of Selenium Cells was given by Professor Thirring.

The following Papers were read :—

1. "The Corrosion Products and Mechanical Properties of Certain Light Aluminium Alloys, as affected by Atmospheric Exposure," by Prof. ERNEST WILSON.

2. "The Distribution of Intensity in a Positive Ray Spectral Line (Part II.)," by M. C. JOHNSON, M.A., M.Sc.

November 12, 1926.

The following Papers were read :—

1. "A Rapid Bolometer made by Sputtering on Thin Films," by H. DEWHURST, A.R.C.S., D.I.C.

2. "A Hygrometer Employing Glycerine," by EZER GRIFFITHS, D.Sc., F.R.S., and J. H. AWBERY, B.A., B.Sc.

3. "The Effect of Working on the Physical Properties of Tungsten," by J. W. AVERY, B.Sc., D.I.C., and C. J. SMITHELLS, D.Sc.

November 26, 1926.

The following Papers were read :—

1. "Electro-Endosmosis and Electrolytic Water Transport," by H. C. Hepburn, B.Sc.

2. "The Input Impedances of Thermionic Valves at Low Frequencies," by L. Hartshorn, A.R.C.S., B.Sc., D.I.C.

December 10, 1926.

The following Papers were read :—

1. "The Principle Governing the Distribution of Current in a System of Linear Conductors," by Frank Wenner, Ph.D.

2. "A Capacitance Bridge of Wide Range, and a New Inductometer," by Albert Campbell, M.A.

A Demonstration of "The Behaviour of Bodies with Non-Conducting Surfaces in Electrostatic Fields" was given by Mr. L. G. Vedy.

January 4, 5 and 6, 1927.

The Annual Exhibition of Apparatus was held by the Physical Society of London and the Optical Society from 3-6 p.m. and from 7-10 p.m. each day.

Discourses were given as follows :—

January 4.

A Lecture on Light and Electricity, as it might have been given in 1709, with the apparatus of the time, by Professor F. N. da C. Andrade.

January 5.

"Progress in Electrical Instrument Design and Construction," by Dr. C. V. Drysdale.

January 6.

"Television," by Mr. J. L. Baird.

January 28, 1927.

The following Papers were read :—

1. " Electrical Polarisation in Selenium Cells and the Effects of Desiccation," by Prof. A. O. RANKINE, D.Sc., and J. W. AVERY.

2. " Synchronous Alternating-current Motors and Mechanical Vibrating Systems Maintained by Thermionic Valves at the Frequency of the Vibrating Systems," by T. G. HODGKINSON, A.M.I.E.E.

3. " On the Spectrum of Ionised Tin," by K. R. RAO, M.A.

4. " On the Spectrum of Doubly Ionised Gallium and Indium," by K. R. RAO, M.A.

A DEMONSTRATION illustrating some Physical Problems connected with Apple Transport was given by Dr. EZER GRIFFITHS, F.R.S.

February 11, 1927.

Annual General Meeting.

GENERAL BUSINESS.

The Report of the Council and that of the Treasurer were presented and unanimously adopted.

REPORT OF THE COUNCIL.

During the year fourteen ordinary Science Meetings have been held at the Imperial College of Science. The Director of the National Physical Laboratory kindly invited the Society to visit the Laboratory on May 22, but this visit had to be cancelled owing to difficulties arising from the industrial situation in the country. For the same reason the Council did not arrange a provincial meeting, like those successfully held in 1924 and 1925 ; but a visit to Bristol will probably be made in 1927.

At the Science Meetings 32 Papers were presented and 12 Demonstrations were given.

Prof. Charles Fabry, who was elected an Honorary Fellow of the Society at the Annual General Meeting, delivered the Eleventh Guthrie Lecture on April 23, the subject being " The Absorption of Radiation by the Upper Atmosphere." About 105 Fellows and Visitors were present.

The average attendance at the meetings of the Society was 54.

The Sixteenth Annual Exhibition, arranged jointly by the Physical and Optical Societies, was held, through the courtesy of the Governing Body, at the Imperial College, on January 5, 6 and 7. Trade exhibits were arranged by seventy-two firms, and the newly instituted Research and Experimental Section contained sixty-one exhibits contributed from twenty sources. Discourses were given by Mr. J. E. Barnard, F.R.S., on "The Search for Ultra-Microscopic Organisms"; by Professor A. F. C. Pollard on "The Mechanical Design of Instruments"; and by Major W. S. Tucker on "Electrical Listening." On the third day the general public were admitted and the total attendance at the Exhibition is estimated at 3,500.

The extension of the scope of the Exhibition, as indicated in the Annual Report for 1925, has been much appreciated.

Dr. D. Owen and Dr. J. H. Vincent have been appointed representatives of the Society on the Board of the Institute of Physics, and Mr. J. Guild and Dr. D. Owen on the Science Abstracts Committee. Mr. F. J. W. Whipple has been reappointed as the Society's representative on the Geophysical Committee of the Royal Astronomical Society, and Prof. E. A. Owen has been appointed to represent the Society on the International X-Ray Unit Committee.

Prof. O. W. Richardson and Mr. F. E. Smith represented the Society at the Coming-of-Age Celebrations of Sheffield University on July 1 and 2, and conveyed to the University an Address of Congratulation on behalf of the Society.

The Council has awarded the Fourth Duddell Medal to Mr. F. Twyman, F.R.S. This will be presented at the Annual General Meeting.

Owing to the rapid growth of the subject, Prof. A. Fowler has not found it possible to prepare the supplement promised for the new edition of his Report on Series in Line Spectra. The Council has therefore arranged for the original Report to be reprinted, together with a new index.

The new agreement, mentioned in the last Annual Report, between the Society and the Institution of Electrical Engineers in respect of "Science Abstracts" has been signed and sealed. The agreement is regarded by the Council as satisfactory.

As a consequence of the deliberations indicated in the last Annual Report concerning the question of changing the name of the Society, the Council has decided to take no formal action in the matter, but to adopt procedure similar to that of the Royal Society in not giving prominence to the words "of London." Commencing with Volume 39 of the Proceedings the words "of London" are to be omitted from all publications and printed papers except where legally necessary on account of the name of the Society remaining "The Physical Society of London," according to the Memorandum of Association.

The Council has entered into negotiations with the Institute of Physics for the purpose of arranging for the routine business of the Society to be performed by the Institute through the agency of the Secretary of the Institute at its new offices at 1, Lowther Gardens, South Kensington.

The Society has sustained a great loss in the death of Mr. W. R. Cooper (elected 1895), who, until recently, was Treasurer of the Society, and had also filled other important offices. The Council on March 26 passed unanimously a resolution of appreciation, which was afterwards adopted by the General Meeting.*

* Proceedings, Vol. 38, p. xvii.

It is necessary also to record with regret the deaths of Sir David Salamons (elected 1876), Mr. J. E. Judson (elected 1877), Mr. R. H. Solly (elected 1878), Prof. W. J. Lewis (elected 1882), Sir Henry Mance (elected 1890), Mr. W. R. Pidgeon (elected 1891), and Dr. S. G. Mostyn (elected 1896), all Life Fellows of the Society; also of Mr. R. W. Forsyth (a former Recorder of the Society, elected 1898), Mr. J. S. Percy (elected 1918) and Mr. F. S. Spiers (elected 1926).

The number of Honorary Fellows on the Roll on December 31, 1926, was 12, the maximum permissible number. At the same date Ordinary Fellows numbered 666 and Students 12. The changes in the Membership of the Society during the year are shown in the appended table :—

——	Total Dec. 31, 1925.	Changes during 1926.			Total Dec. 31, 1926.
Honorary Fellows...	11	Elected		1	
		Net increase		1	12
Ordinary Fellows ...	640	Elected		38	
		Student transfers		9	
				47	
		Deceased	11		
		Resigned or lapsed ...	10		
				—21	
		Net increase		26	666
Students	16	Elected		5	
		Transferred to Fellowship...		9	
		Net decrease		4	12
Total Membership	667	Net increase		23	690

REPORT OF THE TREASURER.

The Expenditure during the past year exceeded the Income by £1 6s. 1d. This is due to the increased cost of the Proceedings. The number of pages in Volume 38 is greater than that in Volume 37 by 139, and the cost of the Proceedings in 1926 was £161 5s. greater than in the preceding year.

The Council is again indebted to the Council of the Royal Society for a grant of £100 towards the cost of publications.

The investments have been valued at market prices through the courtesy of the Manager of the Charing Cross Branch of the Westminster Bank. Owing to the rise in value of securities during the year, the market value of the Society's investments (including the Trust Funds) increased during the twelve months by £11.

INCOME AND EXPENDITURE ACCOUNT.

From January 1st to December 31st, 1926.

1925. £ s. d.	EXPENDITURE.	£ s. d.	£ s. d.
	To		
513 0 0	" Science Abstracts " (Institution of Electrical Engineers, 1926)		434 0 0
	Ordinary Publications :—		
892 1 1	" Proceedings "	1,053 6 1	
70 5 0	" Bulletin "	73 3 3	
102 8 7	General	92 17 10	
			1,219 7 2
93 1 2	Postage of Publications		115 9 4
62 1 1	Reporting	61 12 3	
29 6 3	Refreshments and Expenses of Ordinary Meetings	37 12 0	
203 14 0	Expenses of Exhibition held jointly with the Optical Society	369 12 7	
28 0 10	Secretary and Treasurer's Expenses	23 16 9	
8 5 1	Periodicals and Library	8 8 4	
1 15 0	Insurance	1 15 0	
2 2 0	*Registered Address.*		
0 5 2	Cheque Books and Charges	0 15 7	
20 15 0	Accountancy Charges and Clerical Assistance	41 15 6	
2 15 9	Sundry Expenses	1 3 4	
			546 11 4
20 0 0	Guthrie Lecture (Honorarium)		20 0 0
10 10 0	*Donation to the 1926 Optical Convention.*		
5 5 0	*Lorentz Memorial.*		
	Participation in "Coming of-Age" Celebrations, Sheffield University		10 6 0
	Optical Society—Exhibition Account		21 0 0
90 7 1	*Excess of Income over Expenditure.*		
£2,155 18 1			£2,366 13 10

1925. £ s. d.	INCOME.	£ s. d.	£ s. d.
	By		
954 0 10	Subscriptions by Fellows*	1,063 3 11	
9 9 0	,, (Voluntary†)	9 9 0	
8 18 6	,, by Students	8 18 6	
42 11 0	,, for " Science Abstracts " and Advance Proofs	52 18 6	
1,014 19 4			1,134 9 11
605 6 10	Sale of Publications (Fleetway Press, Ltd.)		484 10 8
	Dividends :—		
	London Midland & Scottish Railway	44 15 4	
	Metropolitan Board of Works	7 0 0	
	Lancaster Corporation Stock	9 12 0	
	New South Wales Stock	10 3 4	
	Southern Railway	28 14 8	
	London & North Eastern Railway	16 0 0	
	India 3½%	17 10 0	
	4% Funding Loan	20 16 0	
	5% War Loan	35 0 0	
		189 11 4	
	Less : Transferred to Duddell Memorial Trust Fund	20 0 0	
162 10 7			169 11 4
40 0 0	Income Tax repayable one year to December 31st, 1926		29 10 11
9 19 8	Interest on Deposit Account		12 16 11
4 5 10	*From Optical Society for Share of Exhibition Expenses.*		
193 2 6	Exhibitors' Payments on account of Exhibition Catalogue		434 8 0
100 0 0	Royal Society Grant for Publications		100 0 0
25 13 4	*Royal Meteorological Society.*		
	Excess of Expenditure over Income, 1926		1 6 1
£2,155 18 1			£2,366 13 10

ROBERT S. WHIPPLE, *Honorary Treasurer.*

Audited and found correct,

T. MATHER
G. H. BAILLIE } *Honorary Auditors.*

February 4th, 1927.

BALANCE SHEET AT DECEMBER 31ST, 1926.

LIABILITIES.

	£	s.	d.	£	s.	d.
Accumulated Fund:—						
Balance as per last account	1,836	7	0			
Entrance Fees, 1926	38	17	0			
	1,875	4	0			
Add Increased Value of Investments	5	0	0			
	1,880	4	0			
Less Excess of Expenditure over Income, 1926	1	6	1			
				1,878	17	11
Life Compositions:—						
Balance as per last Account	2,205	10	0			
Added during the year	84	0	0			
				2,289	10	0
Duddell Memorial Trust Fund as per last Account	428	12	9			
Add Increased Value of Investments	1	0	0			
				429	12	9
W. F. Stanley Trust Fund as per last Account	423	0	0			
Add Increased Value of Investments	5	0	0			
				428	0	0
Sundry Creditors				253	18	0
Subscriptions paid in advance				38	15	10
				£5,318	14	6

ASSETS

	£	s.	d.	£	s.	d.
Investments at Market Value on date:—						
£399 London Midland & Scottish Railway 4 per cent. Debenture Stock	319	0	0			
£1,000 London Midland and Scottish Railway 4 per cent. Preference Stock	740	0	0			
£200 Metropolitan Board of Works 3½ per cent. Stock	192	0	0			
£400 Lancaster Corporation 3 per cent. Redeemable Stock	276	0	0			
£254 2s. 9d. New South Wales 5 per cent. 1935-55	240	0	0			
£300 Southern Railway Preferred Ordinary Stock	234	0	0			
£442 Southern Railway Deferred Ordinary Stock	194	0	0			
£150 Southern Railway 5 per cent. Debenture Stock	150	0	0			
£500 London & North Eastern Railway 4 per cent. Debenture Stock	377	0	0			
£500 India 3½ per cent. Stock	355	0	0			
£650 4% Funding Loan, 1960-90	552	0	0			
£300 5% War Loan 1929/47 inscribed, "A" Account	302	0	0			
£400 5% War Loan 1929/47 inscribed, "B" Account (Duddell Memorial Fund)	403	0	0			
				4,334	0	0
Stock of Publications (as per Treasurer's valuation)				400	0	0
Subscriptions due	36	10	3			
Due from Fleetway Press (Contra)	179	17	0			
Due from Customs and Excise for Income Tax Reclaim	27	10	10			
Paid on Account 1927 Exhibition	20	0	0			
				263	18	1
Cash at Bankers	317	13	7			
Cash in hand (Treasurer)	0	8	10			
Cash in hand (Secretary)	2	14	0			
				320	16	5
				£5,318	14	6

ROBERT S. WHIPPLE, *Honorary Treasurer.*

Audited and found correct,

T. MATHER
G. H. BAILLIE } *Honorary Auditors.*

February 4th, 1927.

Note.—The value of the Society's library has not been brought into the Balance Sheet.

LIFE COMPOSITION FUND AT DECEMBER 31ST, 1926.

	£	s.	d.
128 Fellows paid £10	1,280	0	0
3 Fellows paid £15	45	0	0
1 Fellow paid £20	20	0	0
1 Fellow paid £20 10s.	20	10	0
14 Fellows paid £21	294	0	0
20 Fellows paid £31 10s.	630	0	0
167	£2,289	10	0

W. F. STANLEY TRUST FUND (FOR THE "BULLETIN").

	£	s.	d.		£	s.	d.
£300 Southern Railway Preferred Ordinary Stock	234	0	0	Carried to Balance Sheet	428	0	0
£442 Southern Railway Deferred Ordinary Stock	194	0	0				
	£428	0	0		£428	0	0

DUDDELL MEMORIAL TRUST FUND.

CAPITAL.

	£	s.	d.		£	s.	d.
£400 War Loan 5% 1929/47 inscribed Stock	403	0	0	Carried to Balance Sheet	403	0	0

REVENUE.

	£	s.	d.		£	s.	d.
Balance at 31st December, 1925	26	12	9	Honorarium to Medallist	20	0	0
Dividends	20	0	0	Balance carried to Balance Sheet	26	12	9
	£46	12	9		£46	12	9

Audited and found correct,

T. MATHER
G. H. BAILLIE } *Honorary Auditors.*

ROBERT S. WHIPPLE, *Honorary Treasurer.*

February 4th, 1927.

ELECTION OF OFFICERS AND COUNCIL.

The following Officers and Members of Council were elected for the year 1927-1928 :—

President.—Prof. O. W. Richardson, M.A., D.Sc., F.R.S.

Vice-Presidents (who have filled the office of President).—Sir Oliver J. Lodge, D.Sc., F.R.S., Sir Richard Glazebrook, K.C.B., D.Sc., F.R.S., C. Chree, Sc.D., LL.D., F.R.S., Prof. H. L. Callendar, M.A., LL.D., F.R.S., Sir Arthur Schuster, Ph.D., Sc.D., F.R.S., Sir J. J. Thomson, O.M., D.Sc., F.R.S., Prof. C. Vernon Boys, F.R.S., Prof. C. H. Lees, D.Sc., F.R.S., Prof. Sir W. H. Bragg, K.B.E., M.A., F.R.S., Alexander Russell, M.A., D.Sc., F.R.S., F. E. Smith, C.B.E., F.R.S.

Vice-Presidents.—E. H. Rayner, M.A., Sc.D., Prof. E. A. Owen, M.A., D.Sc., D. Owen B.A., D.Sc., Prof. F. L. Hopwood, D.Sc.

Secretaries.—Prof. A. O. Rankine, O.B.E., D.Sc., Imperial College of Science and Technology ; J. Guild, A.R.C.S., D.I.C., National Physical Laboratory, Teddington, Middlesex.

Foreign Secretary.—Sir Arthur Schuster, Ph.D., Sc.D., F.R.S.

Treasurer.—R. S. Whipple, 45, Grosvenor Place, S.W.1.

Librarian.—J. H. Brinkworth, M.Sc., A.R.C.S., Imperial College of Science and Technology.

Ordinary Members of Council.—R. W. Paul, Prof. A. M. Tyndall, D.Sc., T. Smith, B.A., A. Ferguson, M.A., D.Sc., J. S. G. Thomas, D.Sc., D. W. Dye, B.Sc., Sir Richard Paget, Bart., Prof. E. N. da C. Andrade, D.Sc., Ezer Griffiths, D.Sc., F.R.S., A. B. Wood, D.Sc.

PRESENTATION OF THE DUDDELL MEDAL.

The PRESIDENT, on behalf of the Council, presented the Duddell Memorial Medal for 1927 to Mr. F. TWYMAN, F.R.S., after making the following remarks :—

The Council of the Physical Society, at its meeting on December 10, 1926, awarded the Fourth Duddell Medal for meritorious work on scientific instruments and materials to Mr. F. Twyman, F.R.S. The firm of Adam Hilger, Ltd., of which Mr. Twyman has for many years been both managing and technical director, enjoys, and enjoys deservedly, a reputation for the production of optical instruments employed in physical research which is not approached by that of any other firm in this or any other country. To quite a remarkable extent the fundamental researches which have led to the formation of the current conceptions of the nature of matter have been carried out with the aid of instruments of the necessary high degree of precision constructed in the Hilger workshops. The production of these instruments has frequently involved the solution of problems which have only been met successfully through Mr. Twyman's persistence and resourcefulness.

In addition to the services rendered to the cause of pure science, Mr. Twyman has carried out notable work on a number of technical problems. Two may be specially mentioned. His investigations on the annealing of glass (which incidentally led to "Twyman's Law" on the influence of temperature upon the mobility of the melt) are of fundamental importance, and his instruments for controlling this operation have been of service to all branches of the glass-making industry. These investigations have been an important factor in securing home supplies of reliable glassware for scientific purposes. Moreover, during the war, they led to a notable increase in the output of optical glass, by substituting for the traditional routine a novel scheme of annealing, which, without any deterioration in the quality of the product, enabled the time occupied in this operation to be greatly reduced.

As another example of technical work, the extensive series of Hilger Interferometers may be mentioned. The Michelson type of interferometer has been modified and adapted to a large number of special uses of interest to the optical industry. By the use of these instruments accurate measurements can now be made of the defects of all manner of optical parts and instruments, whether these defects are due to faulty design, imperfect workmanship or defective material. It is characteristic of Mr. Twyman that these new instruments were immediately used not merely to measure the defects, but also as a means of removing them.

VOTES OF THANKS.

The following votes of thanks were carried by acclamation: To the Hon. Auditors (proposed by Prof. A. M. **TYNDALL**, seconded by Mr. J. **BRINKWORTH**), to the retiring Officers and Council (proposed by Dr. J. S. **ANDERSON**, seconded by Dr. **EZER GRIFFITHS**), to the Governors of the Imperial College of Science (proposed by Dr. J. **VINCENT**, seconded by Mr. R. W. **PAUL**).

ORDINARY MEETING FOLLOWING THE ANNUAL GENERAL MEETING.

The Presidential address was delivered by Prof. O. W. **RICHARDSON**, M.A., D.Sc., F.R.S., who took as his subject, "The Present State of Atomic Physics."

A vote of thanks to the Lecturer was proposed by Prof. **CH. FABRY**, seconded by Mr. F. **TWYMAN**, and carried by acclamation.

February 25, 1927.

The **TWELFTH GUTHRIE LECTURE** was given by Prof. Sir **ERNEST RUTHERFORD**, O.M., D.Sc., P.R.S., who took as his subject, "Atomic Nuclei and Their Transformations."

A vote of thanks to the Lecturer was proposed by Sir **RICHARD T. GLAZEBROOK**, F.R.S., seconded by Mr. J. H. **JEANS**, Sec. R.S., and carried by acclamation.

March 11, 1927.

The following Papers were read :—

1. "The Measurement of the Absorption Coefficients of Light Filters," by G. M. B. Dobson, D.Sc., and I. O. Griffith, M.A.

2. "A Comparison of the Behaviour in Thermal Diffusion of Nitrogen and Carbon Monoxide, and of Nitrous Oxide and Carbon Dioxide," by T. L. Ibbs, M.C., Ph.D., and L. Underwood, M.Sc.

3. "The Relighting of a Neon Lamp when Momentarily Extinguished at Voltages below the Striking Potential," by R. R. Nimmo, M.Sc.

4. "The Electrification of Dust Clouds," by G. B. Deodhar, M.Sc.

March 25, 1927.

E. H. Rayner, M.A., D.Sc., in the Chair.

The following Papers were read :—

1. "Acoustical Experiments with a Mechanical Vibrator," by E. Mallett, D.Sc.

2. "The Stationary Wave Method of Measuring Sound Absorption at Normal Incidence," by E. T. Paris, D.Sc., F.Inst.P.

3. "A Ball and Tube Flowmeter Suitable for Pressure Circuits," by J. H. Awbery, B.A., B.Sc., and Ezer Griffiths, D.Sc., F.R.S.

A Demonstration of the Astrolabe and some other Mediaeval Surveying and Navigational Instruments was given by Allan Ferguson, M.A., D.Sc.

April 8, 1927.

D. Owen, B.A., D.Sc., in the Chair.

The following Papers were read :—

1. "A Gas Analysis Instrument based on Sound-Velocity Measurement," by Ezer Griffiths, D.Sc., F.R.S.

2. "The Scattering of X-Rays and the 'J' Phenomenon," by B. L. Worsnop, B.Sc.

3. "The Characteristics of Thermionic Rectifiers," by Prof. C. L. Fortescue.

May 13, 1927.

The following Papers were read :—

1. "The Theory of Luminescence in Radio-active Luminous Compounds," by J. W. T. WALSH, M.A.

2. "Distortion of Resonance Curves of Electrically Driven Tuning Forks," by E. MALLETT, D.Sc.

A DEMONSTRATION of an Electromagnetic Relay, with Separate Make and Break Points, for Temperature Regulations, was given by Mr. J. GUILD.

May 27, 1927.

The following Papers were read :—

1. "A Duplex Reversal Key with Mercury Contacts," by EZER GRIFFITHS, D.Sc., F.R.S., and EDGAR A. GRIFFITHS.

2. "The Measurement of the Inductances of Four-terminal Resistance Standards," by L. HARTSHORN, A.R.C.S., B.Sc., D.I.C.

3. "Magnetic Disturbances and Aurora as observed by the Australian Antarctic Expedition at Cape Denison in 1912 and 1913," by C. CHREE, Sc.D., LL.D., F.R.S.

4. "Series in the Spectrum of Trebly-ionised Tin (Sn IV)," by K. R. RAO, M.A.

A DEMONSTRATION of the Production of Splashes by Electric Discharge was given by Mr. G. L. ADDENBROOKE.

June 3, 1927.

D. OWEN, B.A., D.Sc., in the Chair.

A LECTURE on the Forthcoming Solar Eclipse was delivered by E. H. RAYNER, M.A., D.Sc.

June 10, 1927.

The following Papers were read :—

1. "The Latent Heat of Evaporation of Sulphur," by J. H. AWBERY, B.A., B.Sc.

2. "The Refraction and Dispersion of Carbon Tetrachloride," by H. LOWERY, M.Sc., F.Inst.P.

3. "Regularities in the Spectrum of Ionised Neon," by P. K. KICHLU, M.Sc.

A DEMONSTRATION of the Schönherr-Hessburgh Nitrogen Fixation Arc was given by Capt. G. I. FINCH.

June 24, 1927.

The following Papers were read :—

1. "Newton's Law for the Emission of Heat in Carbon Dioxide," by SYBIL MARSHALL, B.Sc., A.R.C.S., D.I.C.

2. "Some Experiments with Sound Waves of High Frequency," by S. R. HUMBY, M.C., M.A.

3. "Some Additional Refinements for Precision Balances," by J. J. MANLEY, M.A.

A DEMONSTRATION of the Use of a Magnetron to Indicate the Rise of Current in an Inductive Circuit, was given by D. OWEN, B.A., D.Sc.

June 28 and 29, 1927.

An EXCURSION to Richmond, Yorkshire, was arranged for the purpose of witnessing the Solar Eclipse of June 29, 1927.

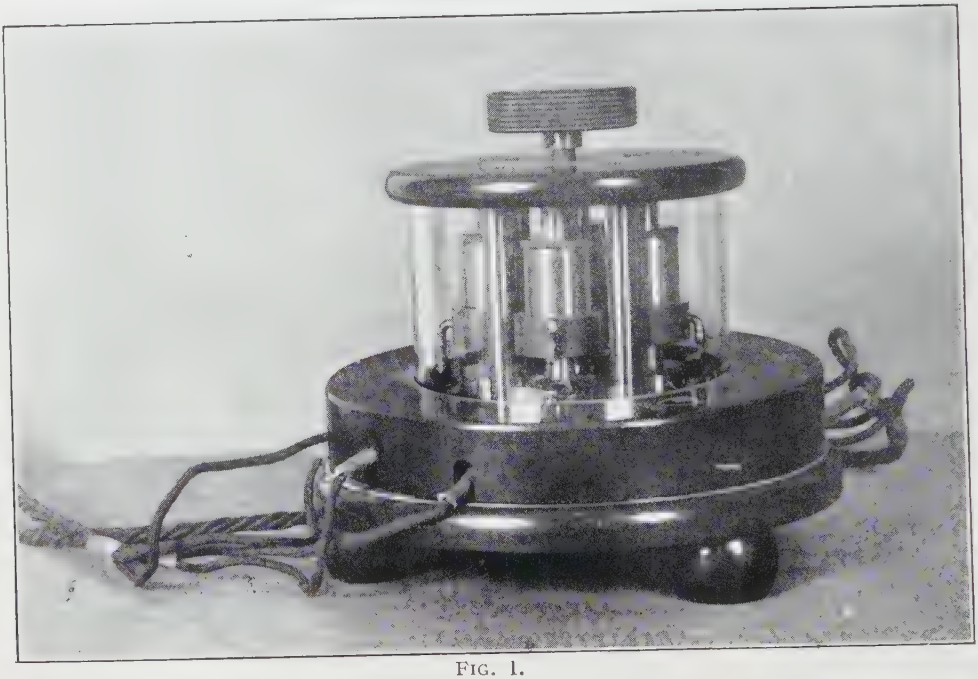

FIG. 1.

[*To face page* 375

XXIX.—A DUPLEX REVERSAL KEY WITH MERCURY CONTACTS.

By Edgar A. Griffiths, Government Physicist, Union of South Africa; and Ezer Griffiths, *D.Sc.*, *F.R.S.*, Physics Department, National Physical Laboratory.

Received April 26, 1927.

Abstract.

The key employs mercury contacts and is enclosed in a glass casing. The two upper fixed contacts consist of downwardly projecting copper rods, the two lower fixed contacts of cups containing mercury, and the two movable contacts of downwardly projecting copper rods (which enter the fixed cups in one position of the switch) surmounted by cups containing mercury (which receive the fixed rods in the other position of the switch). The connections are those of a reversing switch, and the middle contacts can be raised or lowered by turning a vertical shaft which is retained in either position by a jockey spring.

In many experiments it is desirable to have the means for reversing two or more circuits without introducing either variable contact resistances or uncertain thermal electromotive forces into the circuits.

The key illustrated in Figs. 1 and 2 was constructed about seven years ago, and has proved to be so convenient in a variety of tests that a brief description of it may be of value to others.

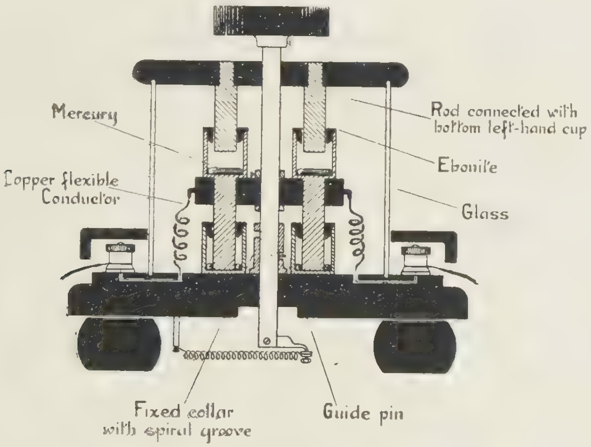
Mercury
Rod connected with bottom left-hand cup
Ebonite
Copper flexible Conductor
Glass
Fixed collar with spiral groove
Guide pin

Fig. 2.

To the base of the key four mercury cups are attached. Above these, and capable of displacement vertically, are four mercury cups with stout copper rods projecting beneath. Fixed to the top of the key are four similar copper rods. These various cups and rods are interconnected as shown in Fig. 3. By a partial turn of the knurled head the movable set of cups is brought up against the four fixed rods projecting from the top of the key. By a reverse turn the four copper rods projecting beneath the movable cups are brought into contact with the bottom of the cups fixed to the base.

The mechanism for translating the partial rotation of the knurled head into a vertical displacement of the cups will be understood from a study of Fig. 2. A guide pin attached to the shaft is constrained to travel along a spiral groove in a fixed collar and thereby the shaft is displaced longitudinally when the knurled head is twisted.

In both positions spring pressure is brought into action to press the contacts together. This is effected by fastening a spring to a radial arm fixed on the lower end of central shaft operating the key. The setting of the radial arm for the " up " and " down " positions respectively is shown in Fig. 4. It will be observed that the maximum extension of the spring corresponds to the midway position of the movable cups, so this is a position of neutral equilibrium and a small movement in either direction allows the spring to pull the contacts together, thus avoiding a variable mercury film resistance.

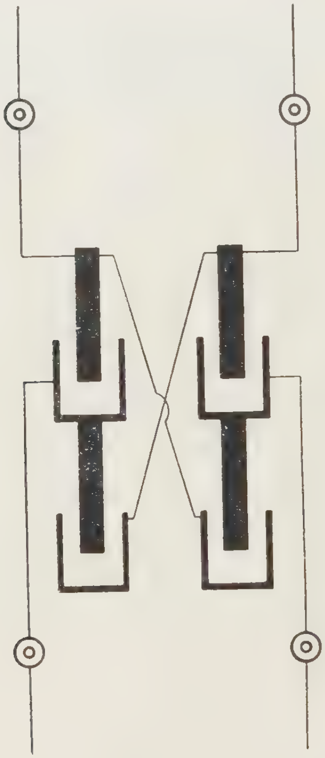

FIG. 3.

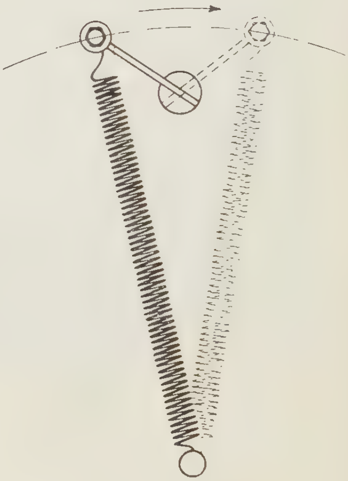

FIG. 4.

To eliminate, as far as possible, thermoelectric effects, the key is cased in a thick glass cylinder and the terminals are covered with an ebonite shield. All terminals, connecting straps, etc., are of copper.

The authors wish to thank Mr. F. H. Murfitt for his suggestions and skilful construction.

XXX.—THE MEASUREMENT OF THE INDUCTANCES OF FOUR-TERMINAL RESISTANCE STANDARDS.

By L. HARTSHORN, *A.R.C.S., B.Sc., D.I.C.*, Electrical Department, National Physical Laboratory.

Received April 26, 1927.

ABSTRACT.

The measurement of the effective inductances of "four-terminal" resistances or "shunts" is discussed. The method of measurement developed in the Paper is an application of the Kelvin Double Bridge, used with alternating current, the phase angle adjustment being obtained by condensers shunting the ratio arms. The procedure to be adopted for eliminating or evaluating corrections due to "leads" is described, and the advantages of the bridge in being free from stray fields, practically independent of frequency, capable of use with almost any desired current strength, and, moreover, very easy to work, are pointed out. Results of measurements made by this method on a series of typical shunts are recorded.

FOUR-terminal resistance standards or "shunts" are widely used in precision alternating current measurements, their function being to provide a potential difference which is in phase with, and proportional to, the current flowing through them. Fig. 1 is a diagrammatic representation of such a shunt. The current I enters and leaves by the "current leads" C_1 and C_2. The potential difference measured is that existing between the "potential terminals" P_1 and P_2. In the ideal case, this potential difference is given by

$$V=RI,$$

where R is the resistance of the shunt. In actual practice, the potential difference V is never exactly in phase with the current I. We may regard it as consisting of two components, a large one, RI, in phase with the current, and a small one, $jwLI$, in quadrature with the current. Thus we may write

$$V=(R+jLw)I,$$

where j is the operator rotating through a right angle, and the frequency is $w/2\pi$. The quantity L in the equation is defined as the inductance of the shunt, while R is the resistance. The object of the present Paper is to describe a method for the measurement of the inductance L.

Two factors contribute to the quantity L—viz., the self-inductance of the shunt between the tapping points p_1 and p_2, and the mutual inductance between the potential leads l_1, l_2, and the whole circuit in which the current I flows. This mutual inductance component may oppose the self-inductance. In order that the inductance L may have a definite value for any particular shunt, it is obviously necessary that the current and potential circuits be arranged so that there can be no mutual inductance between the connecting leads which are attached to C_1 and C_2, and those attached to P_1 and P_2. Thus, the two current terminals must be near together, as also must the two potential terminals, and moreover these two pairs of terminals must not be near each other. In what follows it will be assumed that these conditions are satisfied. When using the shunts, the external leads connected to the potential terminals must be twisted together, and the leads to the current terminals must be similarly treated, since any open loop in the leads is likely to affect the mutual inductance between the potential and current circuits, and so have the effect of altering the value of L.

PREVIOUS METHODS.

A number of methods of measurement of the self-inductances of standard shunts has already been described. A. Campbell has given a general account of these in Glazebrook's Dictionary.* At the National Physical Laboratory, two alternating-current potentiometer methods, developed by Mr. Campbell,† have been in use for some years. These methods make use of a mutual inductance as a standard of phase angle, and as it is generally necessary to work at telephonic frequency, errors due to impurity of the mutual inductance are liable to occur. The measurement is in any case a difficult one, since the circuits contain a number of inductive coils, and it is essential to make sure that the stray fields of these coils are not introducing an undesirable E.M.F. into any part of the circuit. Induction directly into the telephone detector is liable to be very troublesome. It was on this account that the author was led to consider the application of the Kelvin Double Bridge to this type of measurement. Arrangements of this bridge for alternating current measurements have been described by Sharp and Crawford ‡ and by Wenner,§ using inductances in series with the ratio arms for the inductance balance. Sharp and Crawford remark that stray field effects are apt to be very serious when this is done, and on that account preferred to use a separately excited dynamometer as detector, obtaining the resistance balance by in-phase excitation, and adjusting for zero deflection, and then deducing the inductance relations by observation of the deflection with quadrature excitation. The procedure adopted by Wenner, though capable of high accuracy appears to be somewhat exacting, since no less than three simultaneous double balances are required, and the stray field difficulty has to be attended to. In the method developed by the author, no inductive coils are used, and thus stray fields are reduced to a minimum. The quadrature balance is obtained by variable condensers shunting the ratio arms. It subsequently appeared that this same condenser adjustment had been used some time ago by Schering,|| but as the development of the method is very different in the two cases, and the method used at the National Physical

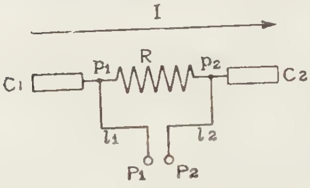

Fig. 1.

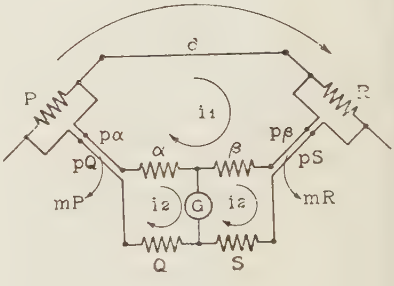

Fig. 2.

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* Dictionary of Applied Physics, Vol. 2, p. 441.

† A. Campbell, Proc. Phys. Soc., Vol. 29, p. 345 (1917).

‡ Sharp and Crawford, Trans. A.I.E.E., Vol. 29, p. 1540 (1910).

§ Wenner, Bull. Bur. Stds., Vol. 8, p. 559 (1912).

|| Schering, E.T.Z., Vol. 34, p. 421 (1917).

Laboratory is particularly easy to work, and need require no very special apparatus, it is considered worth while to describe it in some detail. Other methods of measuring the inductances of shunts are described by Wenner, Weibel and Silsbee.* These, like Campbell's methods, are independent of standards of calculated inductance, but require special apparatus, and are not likely to be very quick in operation.

THEORY OF THE METHOD.

Fig. 2 is a diagrammatic representation of the bridge. P and R are four-terminal shunts to be compared for inductance. Q and S are the main ratio arms, and α and β the auxiliary ones. Let $P, R, Q, S, \alpha, \beta$ be the impedance operators of the various coils. The potential terminals of the coil P are connected to the ratio coils αQ by means of twinned leads, and there is a similar pair of leads connecting the coils β and S to the potential points of R. Let p_α p_β, p_Q, p_S be the impedance operators of these leads, and m_P, m_R their mutual operators; also let d be the impedance operator of the link connecting the current terminals of P and R. Let the mesh currents be i, i_1, i_2, as in Fig. 2. When the bridge is balanced the currents in the meshes αGQP, βRSG must be equal, as indicated (i_2).

Applying Kirchhoff's equations to the network we obtain, as conditions of balance the equations

$$(i+i_2)P+(i_2-i_1)(\alpha+p_\alpha+m_P)+i_2(Q+p_Q+m_P)=0, \quad \ldots \quad (1)$$

$$(i+i_2)R+(i_2-i_1)(\beta+p_\beta+m_R)+i_2(S+p_S+m_R)=0, \quad \ldots \quad (2)$$

$$(i+i_1)d-(i_2-i_1)(\alpha+p_\alpha+\beta+p_\beta)-i_2(m_P+m_R)=0. \quad \ldots \quad (3)$$

Rewriting (1) and (2) we have

$$(i+i_1)P+(i_2-i_1)(P+\alpha+p_\alpha+m_P)+i_2(Q+p_Q+m_P)=0, \quad \ldots \quad (4)$$

$$(i+i_1)R+(i_2-i_1)(R+\beta+p_\beta+m_R)+i_2(S+p_S+m_R)=0. \quad \ldots \quad (5)$$

Now let the connector d be removed, and the bridge again balanced. The mesh currents are now i_3 and i_4 (Fig. 3), and the conditions of balance are

$$(i_3+i_4)(P+\alpha+p_\alpha+m_P)+i_4(Q+p_Q+m_P)=0, \quad \ldots \quad (6)$$

$$(i_3+i_4)(R+\beta+p_\beta+m_R)+i_4(S+p_S+m_R)=0, \quad \ldots \quad (7)$$

whence

$$(P+\alpha+p_\alpha+m_P)/(R+\beta+p_\beta+m_R)=(Q+p_Q+m_P)/(S+p_S+m_R)=k \text{ (say)} \quad . \quad (8)$$

If now the bridge arms can be adjusted so that the bridge is balanced both when the link d is inserted, and when it is removed, then equations (3), (4), (5) and (8) must hold for all values of the current i. Now, evaluating (4) $-k\times(5)$, we find, on substituting (8),

$$(i+i_1)(P-kR)=0.$$

Thus, the condition for simultaneous balance is

$$P/R=k=(Q+p_Q+m_P)/(S+p_S+m_R)=Q'/S' \quad \ldots \quad (9)$$

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* Wenner, Weibel and Silsbee, Bull. Bur. Stds., Vol. 12, p. 11 (1915).

P, R, Q', S' are vector impedances. Let their phase angles be $\theta_P, \theta_R, \theta_Q', \theta_S'$. Then in order that equation (9) may hold, the relation between the phase angles must be

$$\theta_P - \theta_R = \theta_Q' - \theta_S'. \quad \ldots\ldots\ldots\ldots \quad (10)$$

If R_P and L_P are the resistance and effective inductance of coil P, we may write, in the usual notation,

$$P = R_P + jwL_P, \text{ and similarly}$$
$$R = R_R + jwL_R$$

The arms Q and S will usually consist of coils of resistance $R_Q R_S$ and inductances $L_Q L_S$, shunted by capacities $C_Q C_S$, in order to obtain the balance. Thus, to a first approximation

$$Q = R_Q + jw(L_Q - C_Q R_Q^2),$$
$$S = R_S + jw(L_S - C_S R_S^2).$$

We have also

$$p_Q = r_Q + jwl_Q,$$
$$p_S = r_S + jwl_S,$$

and since m_P and m_R represent practically pure mutual inductances

$$m_P = jwM_P,$$
$$m_R = jwM_R.$$

Q' and S' in equation (9) are evidently given by

$$Q' = R_Q + r_Q + jw(L_Q + l_Q + M_P - C_Q R_Q^2),$$
$$S' = R_S + r_S + jw(L_S + l_S + M_R - C_S R_S^2).$$

Now, $PRQ'S'$ represent impedances of very small phase angle. Thus, to a sufficient approximation for all practical purposes we may write

$$\theta_P = \tan \theta_P = L_P w / R_P = \tau_P w,$$

where τ_P is the time constant of P, and so on. Thus equation (10) may be written

$$L_P/R_P - L_R/R_R = (L_Q + l_Q + M_P)/(R_Q + r_Q) - (L_S + l_S + M_R)/(R_S + r_S)$$
$$- C_Q R_Q^2/(R_Q + r_Q) + C_S R_S^2/(R_S + r_S),$$

or, since the leads resistances r_Q and r_S are negligible compared with R_Q and R_S

$$L_P/R_P - L_R/R_R = L_Q/R_Q - L_S/R_S + C_S R_S - C_Q R_Q + \{(l_Q + M_P)/R_Q - (l_S + M_R)/R_S\} \quad (11)$$

This is the equation to be used for determining L_P/R_P. The quantities L_R/R_R, L_Q/R_Q, L_S/R_S, $C_S R_S$, $C_Q R_Q$, are usually known, while the term in brackets may be regarded as a correction term depending on the self and mutual inductances of the leads.

This correction term is usually very small, and may be neglected in practice, except for work of the highest precision. In such cases it may be evaluated as follows. Suppose that the conditions of simultaneous balance have been obtained as previously described. Let C_S be the reading of the condenser shunting the arm S. Now transfer the current supply leads from the points (1) (2) to the points (3) (4) (Fig. 3), and, the link d being removed, again balance by varying the arm S. Let C_S' be the new reading of the S condenser. The value of R_S will only need altering by an amount which is negligible, from the point of view of phase angle. The original condition of balance is given by (8). If the mesh currents i_3, i_4 become i_5 i_6 in the final balance, we have, as the equations for balance,

$$(i_5+i_6)\,(P+p_{\mathrm{Q}}+p_\alpha+2m_{\mathrm{P}}+\alpha)+i_6Q=0,$$
$$(i_5+i_6)\,(R+p_{\mathrm{S}}+p_\beta+2m_{\mathrm{R}}+\beta)+i_6S'=0,$$

giving
$$(P+\alpha+p_{\mathrm{Q}}+p_\alpha+2m_{\mathrm{P}})/(R+\beta+p_{\mathrm{S}}+p_\beta+2m_{\mathrm{R}})=Q/S',\quad .\quad .\quad .\quad .\quad (12)$$
as against the original condition,

$$(P+\alpha+p_\alpha+m_{\mathrm{P}})/(R+\beta+p_\beta+m_{\mathrm{R}})=(Q+p_{\mathrm{Q}}+m_{\mathrm{P}})/(S+p_{\mathrm{S}}+m_{\mathrm{R}}).\quad .\quad .\quad (8)$$

Now, each of these equations (8) and (12) involves a phase angle equation of the same form as (10). We may write down by inspection the difference of these two phase angle or time constant equations, remembering that the lead resistances are negligible compared with the coil resistances, as

$$({}'_{\mathrm{Q}}+M_{\mathrm{P}})/(R_{\mathrm{P}}+R_\alpha)-(l_{\mathrm{S}}+M_{\mathrm{R}})/(R_{\mathrm{R}}+R_\beta)$$
$$=-(l_{\mathrm{Q}}+M_{\mathrm{P}})/R_{\mathrm{Q}}+(l_{\mathrm{S}}+M_{\mathrm{R}})/R_{\mathrm{S}}+(C_{\mathrm{S}}'-C_{\mathrm{S}})R_{\mathrm{S}},$$

or,
$$\frac{(l_{\mathrm{Q}}+M_{\mathrm{P}})}{R_{\mathrm{Q}}}\left(1+\frac{R_{\mathrm{Q}}}{R_{\mathrm{P}}+R_\alpha}\right)-\frac{(l_{\mathrm{S}}+M_{\mathrm{R}})}{R_{\mathrm{S}}}\left(1+\frac{R_{\mathrm{S}}}{R_{\mathrm{R}}+R_\beta}\right)=(C_{\mathrm{S}}'-C_{\mathrm{S}})R_{\mathrm{S}}.$$

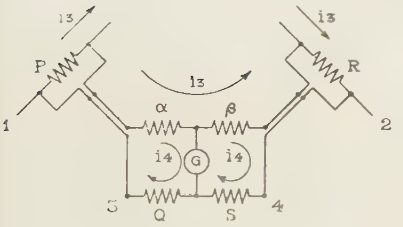

Fig. 3.

Now to a first approximation, the resistances obey the usual relation for the Kelvin Double Bridge, viz.,

$$R_{\mathrm{P}}/R_{\mathrm{R}}=R_{\mathrm{Q}}/R_{\mathrm{S}}=R_\alpha/R_\beta.$$

Hence we have

$$\{(l_{\mathrm{Q}}+M_{\mathrm{P}})/R_{\mathrm{Q}}-(l_{\mathrm{S}}+M_{\mathrm{R}})/R_{\mathrm{S}}\}$$
$$\{1+R_{\mathrm{Q}}/(R_{\mathrm{P}}+R_\alpha)\}=(C_{\mathrm{S}}'-C_{\mathrm{S}})R_{\mathrm{S}}.$$

Thus, the correction term required is given by

$$\{(l_{\mathrm{Q}}+M_{\mathrm{P}})/R_{\mathrm{Q}}-(l_{\mathrm{S}}+M_{\mathrm{R}})/R_{\mathrm{S}}\}=(R_{\mathrm{P}}+R_\alpha)\times(C_{\mathrm{S}}'-C_{\mathrm{S}})R_{\mathrm{S}}/(R_{\mathrm{P}}+R_{\mathrm{Q}}+R_\alpha)\quad .\quad (13)$$

In practice R_{P} is usually small compared with R_{Q} and R_α, which are equal. We then have the very simple relation

$$\text{Correction}=(C_{\mathrm{S}}'-C_{\mathrm{S}})R_{\mathrm{S}}/2\quad .\quad .\quad .\quad .\quad .\quad .\quad .\quad .\quad .\quad .\quad (14)$$

PRACTICAL DETAILS AND PROCEDURE.

It is evident from equations (11) and (13) that we have a means of finding the difference of time constant of two four-terminal shunts P and R, in terms of the time constants of the coils Q and S, and the values of their resistances and the capacities shunting them, when the above conditions are fulfilled. For Q and ` we can use ordinary non-inductive ratio arms, of the order of 100 ohms and 1,000 ohms. Their time constants are likely to be of the order 10^{-8}, and the difference between them can be measured, if necessary, with an error of about 10^{-9}. Thus, since a standard shunt is not likely to have a time constant much less than 10^{-7}, the values of the time constants of Q and S are not usually of great importance.

The actual arrangement used is shown in Fig. 4. The two resistances P and R are connected in series to the current supply by means of their " current terminals." The go and return connecting leads are kept as close together as possible, so as to avoid any strong magnetic field. The ratio coils Q, S, α, β, are shielded coils of the type used in ordinary alternating current bridge work. Generally a ratio of 100 ohms : 1,000 ohms was used. These coils were placed some distance (say, 1 metre) away from the resistances P and R, so that the possibility of any undesirable stray field effects from the main circuit is further reduced. The potential terminals of P and R are connected to the ratio arms, by means of twinned flexible leads as shown. In some cases these leads were two or three metres long, and it is on this account that the correction for their self and mutual inductances was evaluated. Since it is necessary to vary the resistances of the ratio arms, small slide wire resistances were included in β and S or α and Q. In most of the experiments made, current of telephonic frequency was used and a telephone receiver was used as the detector G. This is convenient, since it allows the necessary sensitivity for time constant to be obtained with a smaller current than is required at lower frequencies. The bridge is, however, independent of frequency to a first approximation, and measurements were also made at a frequency of 50 ∼, in which case a vibration galvanometer was used as detector. The phase angle adjustments were made by means of two variable air condensers, C_S and C_β, in Fig. 4. These had maximum values of about 0·002 μF. In some cases their ranges had to be extended by the use of fixed mica condensers in parallel with them. In order to locate definitely the potentials of the various coils with respect to earth, the outer current terminals of P and R were shunted by two resistances X and Y in series, their common point E being earth connected. The values of X and Y were chosen to satisfy approximately the relations $X/Y=P/R=Q/S=\alpha/\beta$. Thus, when the bridge is balanced, the common points of PR, $\alpha\beta$, QS will be approximately at the same potential as E. The detector G will, therefore, be at earth potential, and no undesirable earth capacity effects are likely to be introduced. The shields of the condensers C_β and C_S were connected to the galvanometer side of β and S respectively. The shields of the coils $\alpha\beta QS$ were earth connected. Under these conditions, the balance point of the bridge is very stable, and the bridge very easy to work. Reversing the connections to the current supply and the detector causes no change in the balance point.

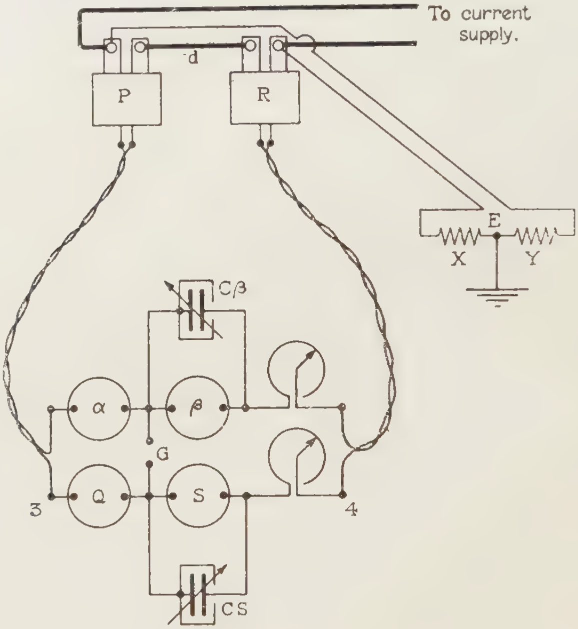

Fig. 4.

The procedure was as follows. The bridge was connected up as in Fig. 4, the link d being made as low in resistance as possible. Balance was obtained by varying the resistance and capacity of the S arm. The link d was then opened, and the bridge again balanced by varying the resistance and capacity of the β arm. The link d was then again joined up and balance once more obtained by varying the S arm. Usually the adjustment required at this stage was only very slight, and the bridge was then found to be balanced when the link was either closed or open. Current was now applied to the bridge at the points (3) and (4) of Fig. 4, the link d being open, and balance again obtained by varying the S arm. The amount of adjustment required for this was only very small. As explained above, it represents the effect of the self and mutual inductance of the leads running up to the potential terminals of P and R. If C_S is the reading of the S condenser for the first simultaneous balance, and C_S' is the final reading of this condenser, we have from equations (11) and (13)

$$\begin{aligned} L_P/R_P - L_R/R_R = {} & L_Q/R_Q - L_S/R_S + C_S R_S - C_Q R_Q \\ & + (R_P + R_\alpha) \times (C_S' - C_S) R_S/(R_P + R_Q + R_\alpha) \quad . \quad . \quad . \quad (15) \end{aligned}$$

In general, it is not necessary to have condensers across both the Q and S arms, and the term $C_Q R_Q$ is thus usually zero. The quantity $(L_Q/R_Q - L_S/R_S)$ may be regarded as a small correction δ_{QS}, which is known, or which can be measured by any of the usual methods. Further, R_P is usually negligible compared with R_Q and R_α, which are equal. The working equation, therefore, becomes

$$\begin{aligned} L_P/R_P - L_R/R_R & = C_S R_S + \delta_{QS} + \tfrac{1}{2}(C_S' - C_S) R_S, \\ & = \tfrac{1}{2}(C_S + C_S') + \delta_{QS}. \end{aligned}$$

The points (3) (4) (Fig. 4) should, of course, be brought as near together as possible, so that current can be brought to them through bifilar twisted leads, which will induce no stray E.M.F.s into the coils $\alpha\beta QS$. It is important to make the link d as low in resistance as possible, for the smaller this resistance compared with P and R, the less is the effect on the balance point of the values of α and β,and, therefore, the easier it is to obtain the condition of simultaneous balance.

THE PRIMARY STANDARD.

It will be observed that the bridge method can only give the difference of the time constants of two shunts. Thus, it is necessary to have at least one shunt of known time constant before values can be obtained for others. The ultimate standard used in these experiments was a 1 ohm four-terminal resistance, the effective inductance of which was calculable from its dimensions. This was designed by Mr. S. Butterworth, who has kindly supplied the following particulars. The resistance consists of a rectangular loop of Eureka wire C_1STUVC_2 (Fig. 5), C_1 and C_2 being the current terminals. Two brass contact pieces X and Y make contact with this loop at the potential points S and V. From the contact pieces X and Y potential leads proceed parallel to the sides of the main resistance loop, o the potential terminals P_1 and P_2. The various wires are located by passing through holes in the ebonite spacing pieces shown in Fig. 5. The current and potential terminals are as far apart as possible, so that the pairs of leads connecting them to the measuring circuit will not induce E.M.F.s into one another. In order to calculate the effective inductance, we have to evaluate (*a*) The self inductance of the rectangular loop $STUV$, between the potential points S and V.

(*b*) The mutual inductance between the potential leads XW, YZ and the sides of the loop $STUV$.

(*c*) The small correction terms due to the extensions C_1S, C_2V, WP_1, and ZP_2 of the leads.

If the dimensions are as shown in Fig. 5 then neglecting the effect of the leads (*c*) the inductance is given by the formula

$$L=4B\log_e\{Dd/R(D+d)\},$$

R being the radius of the wire. The actual values were $D=9{\cdot}68$ mm., $d=4{\cdot}64$ mm., $B=10{\cdot}0$ cm., $R=0{\cdot}154$ mm., giving L=130 cm.=0·130 μ**H**. With the dimensions of the leads shown in Fig. 5 the correction due to these was found by calculation to be $-0{\cdot}006\mu$H. Thus the final value for the inductance is $L=0{\cdot}124\mu$**H**.

The time constants of 1 ohm resistance standards were determined by direct comparison with this calculated standard, using the method described above, with equal ratio arms, either 100 : 100 ohms, or 1,000 : 1,000 ohms. Standards of 0·1 ohm resistance were compared with a 1 ohm resistance using a ratio of 100 : 1,000 ohms; 0·01 ohm standards were compared with a 0·1 ohm standard using the same ratio, and so on down to 0·0005 ohm. Ratios other than 10 : 1 are sometimes used, but in general this is the most convenient. The accuracy in time constant obtainable on the shunts of very low resistance is of course somewhat less than that on shunts of 1 ohm and 0·1 ohm, since the errors of the various intermediate steps will be cumulative. The time constants of these low resistance shunts are, however, always higher than those of greater resistance, and it is not possible to use them with the same degree of precision, so that this point is not of great importance.

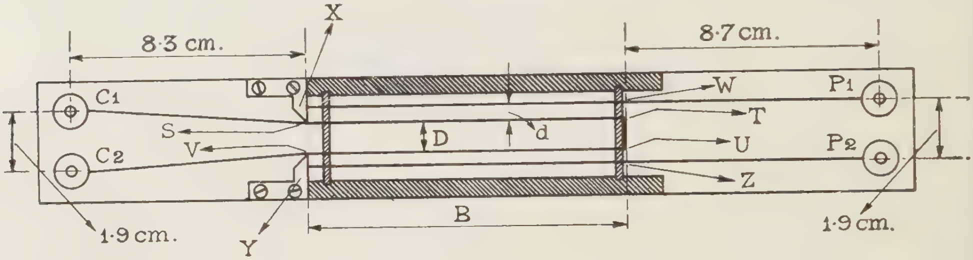

Fig. 5.

When no standard of calculable inductance is available, it is possible to proceed as follows. Take an ordinary 10 ohm resistance coil, and use it as a four terminal resistance, simply by using its terminals as both current and potential terminals. Its inductance as a four-terminal resistance may be taken as practically the same as its ordinary value as a two-terminal coil, which is readily measurable. There will, of course, be small errors due to the mutual inductance between the coil and the potential leads used, but if each pair is twisted together, and they are disposed so as to make this mutual inductance small, the effect on the time constant L/R will be negligible, owing to the comparatively large value of R. A 1 ohm shunt may thus be evaluated in terms of a 10 ohm coil used in this way, and results so obtained were found to agree with those obtained by comparison with the calculated standard with an error of less than 1×10^{-8} in time constant.

TYPICAL RESULTS.

The time constants and effective inductances of a number of four-terminal resistances of various types have been determined by this method. The resistances varied from 1·0 ohm and 0·1 ohm for coils such as are used in alternating current bridge and potentiometer work, to 0·0005 ohm and 0·001 ohm, for shunts capable of carrying one or two thousand amperes, such as are used for power measurements, and for testing current transformers. The results are given here, since they may be regarded as being fairly typical, and as indicating therefore the probable order of error involved in using apparatus of the particular type in question.

The measurements were nearly all made with current of frequency 800 cycles per second. The use of high frequency increases the value of the quadrature component of voltage, relatively to the in-phase component, and thus makes the measurement of this quadrature component in a sense easier. In making measurements with shunts of 1 and 0·1 ohms, a current of 0·25 ampere gave sufficient sensitivity. For the 0·001 and 0·0005 ohm shunts, a current of 5 amperes was required. The detector was an ordinary 120 ohm telephone receiver of the Bell type.

The heavy current resistance standards are used almost exclusively at power frequencies, and thus the value of the inductance at 50 cycles per second is the value actually required. It was found, however, that for all the resistances tested the inductance is sensibly independent of the frequency up to about 1,000 cycles per second. It is an advantage of the bridge that the balance point is practically independent of the frequency, and thus to find out whether the inductance varies appreciably with the frequency, it is only necessary to raise the frequency from, say, 500∼/sec. to 800∼/sec., and to note the change of balance point. In general the resistances are found to change slightly, but not so the inductances.

The possibility of the effective inductance changing with varying current strengths must also be considered. Any change in the inductance as the current strength is increased can only be due to one of two things, viz. :—

(*a*) A change in the distribution of the lines of flow of the current ;

(*b*) A change in the geometrical configuration of the shunt. Such changes will not occur in a well-designed shunt. Changes in the distribution of the lines of current flow will, of course, give rise also to changes of resistance, and these are easily detected. Bending and warping of the resistance alloy does occur in some cases, due to the heating effect of the current, but such shunts cannot be regarded as standards, from the point of view of phase angle, since the value of the phase angle will always be subject to considerable uncertainty. The inductance of a well-designed shunt must therefore be independent of the current strength. The method does, of course, present the advantage that it may be used with a most any desired value of current. It is merely necessary to obtain a shunt capable of use as a comparison standard, which will carry the maximum current required without distortion.

As an illustration of the order of the quantities involved in these measurements, the following observations, made on a bridge set up for the comparison of two shunts of resistances 0·1 and 1 ohm respectively, are given,

R_P=0·1 ohm.	R_Q=100 ohm.	R_α=50 ohms.
R_R=1·0 ,,	R_S=1,000 ,,	R_β=500 ,,

The bridge arms S and β were provided with small slide wire adjustments of resistance, and were shunted with variable air condensers. When the first simultaneous balance was obtained, the reading of this condenser C_S was 1,330 $\mu\mu$F$=1{,}330\times10^{-12}$ farad. The current supply leads were now transferred to the points (3) (4), Fig. 3, the link d removed, and balance again obtained by adjusting the arm S. The new reading of the condenser was $C_S'=1{,}342$ $\mu\mu$F. The readings of the various resistances R_QR_S, etc., were not noted in detail, since they were always within about 0·5 per cent. of their nominal values, and thus their actual values are of no consequence from the point of view of inductance measurement. Similarly, the reading of the condenser across the arm β is not required. The time constants of the ratio arms Q and S were known from two-terminal measurements to be $0{\cdot}6\times10^{-8}$, and $1{\cdot}3\times10^{-8}$ respectively, thus giving rise to the correction term $\delta_{QS}=L_Q/R_Q-L_S/R_S=-0{\cdot}7\times10^{-8}$. The time constant of the 1 ohm standard R, had been found by comparison with the calculated standard to be $L_R/R_R=1{\cdot}6\times10^{-8}$. Thus, from equation (14) we find

$$L_P/R_P-1{\cdot}6\times10^{-8}=-0{\cdot}7\times10^{-8}+133{\cdot}_0\times10^{-8}+\tfrac{1}{3}\times12\times10^{-9},$$

giving $L_P/R_P=134{\cdot}_3\times10^{-8}$, and therefore $L_P=0{\cdot}134\mu$H. The various correction terms are seen to be almost negligible. The values obtained for a series of typical shunts are given in Table I.

TABLE I.—*Effective Inductances of Typical Shunts.*

Resistance (ohms).	Type.	Maximum current (amperes).	Time constant (second).	Effective inductance (microhenry).
1·0	N.P.L.	0·5	$1{\cdot}6\times10^{-8}$	0·016
1·0	Drysdale-Tinsley.	3	$7{\cdot}5\times10^{-7}$	0·75
0·1	,,	22	$13{\cdot}4\times10^{-7}$	0·134
1·0	N.P.L. Box.	2	$2{\cdot}3_1\times10^{-7}$	0·231
0·1	,,	20	$2{\cdot}3\times10^{-7}$	0·023
0·04	,,	50	$2{\cdot}0\times10^{-7}$	$0{\cdot}008_0$
0·02	N.P.L. Tube.	100	$2{\cdot}9\times10^{-7}$	$0{\cdot}005_8$
0·01	,,	200	$4{\cdot}1\times10^{-7}$	$0{\cdot}004_1$
0·004	,,	500	$15{\cdot}5\times10^{-7}$	$0{\cdot}006_2$
0·002	,,	1,000	11×10^{-7}	$0{\cdot}002_2$
0·001	,,	2,000	32×10^{-7}	$0{\cdot}003_2$
0·005	Drysdale-Tinsley.	200	$2{\cdot}2\times10^{-7}$	$0{\cdot}001_1$
0·001	,,	700	14×10^{-7}	$0{\cdot}001_4$
0·0005	,,	1,000	25×10^{-7}	$0{\cdot}001_3$

The shunts described in Table I as being of N.P.L. Box Type are air-cooled shunts, consisting of a number of bifilar loops in parallel. As is to be expected, the time constant is practically independent of the actual resistance, since all the loops are exactly similar and the required resistance is obtained simply by putting an appropriate number in parallel. The " N.P.L. Tube " type of shunt is the Paterson-Rayner* water-cooled tubular shunt.

The inductances of some of these shunts can be calculated approximately from their dimensions—e.g., the Drysdale-Tinsley 0·001 ohm shunt consisted of two concentric cylinders, joined together at one end. The current is led in and out at the other end by " current leads," consisting of a pair of copper plates, parallel, and as near together as possible, so that they will produce practically no stray magnetic field, and the potential leads are very short, so that the mutual inductive effect associated with them is practically negligible. The mean diameter of the cylinder was 16 cm.$=2R$, say. Their length (l) was 15 cm., and the radial distance between them (t) was 0·35 cm. If a current I flows down the inner tube and up the outer one, then evidently the field is zero everywhere except in the annular space between the tubes. The mean field intensity in this region is $2I/R$, and thus the total flux is $2Il/R$. The inductance, or flux per unit current, is thus approximately given by $L=2lt/R=1{\cdot}3$ cm.$=0{\cdot}0013$ μH. The measured value was 0·0014 μH. A few calculated values given by Paterson and Rayner for their water-cooled shunts are given in Table II, together with the corresponding observed values.

TABLE II.—*Observed and Calculated Values of Inductance for Paterson-Rayner Shunts.*

Shunt.	Inductance.	
	Calculated (cm.).	Observed (cm.).
0·02 ohm	5·4	5·8
0·01 ,,	3·4	4·1
0·002 ,,	3·7	2·2
0·001 ,,	3·0	3·2

In these cases, the agreement between the two values is not perfect, although it would be near enough for many practical purposes. The differences are probably due partly to the fact that the conditions required by the formula used for the calculations are only imperfectly realised in the shunts (there is in practice a gap in the middle of the potential sheath), and partly to the fact that the insulation between the tube and sheath has been renewed since the calculations were made, and that its thickness is now almost certainly somewhat different from its original value. There is little doubt that the inductances of such shunts can now be measured with an accuracy greater than that obtainable by approximate calculations.

DISCUSSION.

Dr. A. RUSSELL congratulated the author on his obtaining definite results for a problem of great practical importance, which defied solution by the method of calculation. He inquired whether the effective inductance measured as described in the Paper included the shunt capacity inherent in the resistances and leads ?

Mr. R. P. FUGE : I would like to add my hearty congratulations to Mr. Hartshorn for his very able and clear Paper. I was going to ask a very similar question to the one that Dr. Russell asked, that is as regards the possibility of the separation of the capacities associated with the inductances, more especially as regards the capacities of the leads ? The author uses very long twisted leads, sometimes three metres long. I lately measured the capacity of twisted wire leads I was using, and similar twisted wire (leads) three metres long would have a capacity of, roughly, 100$\mu\mu$F. I would like to ask the author what effect that capacity (in the leads) would have ?

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* C. C. Paterson and E. H. Rayner, Jour. I.E.E., Vol. 42 (1909) ; or, N.P.L. Collected Researches, Vol. 6, p. 99 (1910).

Mr. G. W. Bowdler pointed out that even a capacity of 100$\mu\mu$F would produce only a negligible time constant when shunted across a moderately small resistance.

Dr. D. Owen said that while A.C. methods of measuring inductance were the most precise they involved the expenditure of much time and the use of expensive apparatus in order to ensure accuracy ; however, the results given in the present Paper conformed to the high standard expected of the National Physical Laboratory. In the measurement of small inductances it was important to eliminate the effect of adventitious capacities, and he noted the simple method, analogous to the Wagner earthing device, which was shown in Fig. 4 of the Paper. The time constant of one of the two 1 ohm resistances in Table I was 50 times smaller than that of the other, so that by careful design much could be done to eliminate reactance. In a standard the resistance and the time constant must both be known accurately. The largest of the time-constants shown in the table corresponded, however, to a voltage error of less than 1 part in 1,000 at electric supply frequencies, and so was negligible for many practical purposes.

The Author, in reply to the discussion, said that the shunt capacity of the standards considered in the Paper was negligible : a capacity of 1$\mu\mu$F shunting 1 ohm gives an effective inductance of ($-1\mu\mu$H), so that even 100$\mu\mu$F would produce a negligible result. With higher resistances attention would have to be given to the length of the leads. The rough Wagner earth shown in the diagram sufficiently prevented errors due to stray earth capacities, but owing to the smallness of the resistances elaborate precautions in this connection were not called for.

XXXI.—MAGNETIC DISTURBANCE AND AURORA AS OBSERVED BY THE AUSTRALASIAN ANTARCTIC EXPEDITION AT CAPE DENISON IN 1912 AND 1913.

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Abstract.

The Paper summarises the results obtained as to the diurnal variation of magnetic disturbance during 1912 and 1913 at Cape Denison (67° 0′ S. lat., 142° 40′ E. long.), the base station of the Australasian Antarctic Expedition. The results are compared with corresponding results from Eskdalemuir and Cape Evans, the base station of the British Antarctic Expedition. The Paper also discusses the relations between magnetic disturbance and aurora at Cape Denison.

§ 1.

In any comparison between aurora and magnetic disturbance we encounter the difficulty that neither phenomenon presents itself naturally as a numerical quantity. Aurora may be confined to a small part of the heavens, or may cover a large part of the sky. It may be only a little way above the horizon, or it may extend to the zenith. It may be nearly stationary, or in rapid motion. The motion may be steady, or it may be of the most confused, turbulent nature. The colour may be a uniform yellow or greenish white, varying slowly in intensity, or it may be brilliant red, green, lilac or other colour, continually altering. The brightness and visibility of aurora depend largely on the absence or presence of moonlight or twilight. A bright aurora may be visible under conditions when faint aurora is not. The presence or absence of cloud, haze, or even snowdrift, may be all important. Unless a continuous outlook is maintained—hardly a possibility with ordinary resources—the accidental occurrence of cloud at an observation hour may prevent an aurora from being seen. In the Antarctic, overcast conditions and blizzard, with drifting snow, sometimes extend over several successive days. When data from a number of years are available, the influence of moonlight on the apparent diurnal variation of aurora should be satisfactorily eliminated ; but assurance that such has been the case can hardly be felt when only a few months' data are available. Cloud and other meteorological phenomena may have a sensible diurnal variation, and may react on the apparent diurnal variation of aurora.

§ 2.

While appreciating all these difficulties, I decided that for any comparison with magnetic phenomena an attempt must be made to assign numerical measures or characters indicative of greater or less auroral intensity. For the purposes of the investigation Sir Douglas Mawson sent me advanced proofs of the log of auroras observed at Cape Denison—the base station of the Australasian Antarctic Expedition—in 1912 and 1913. To each observation of aurora I assigned a character figure, on the scale 0·5, 1·0, 1·5 and 2·0, answering to what may be roughly described as very faint, faint, bright and very bright aurora. The judgment was based entirely on the descriptive language. No attention was paid to the altitude or type, except that glows and patches were assumed of inferior intensity as compared with arches and curtains. Some allowance was made for unfavourable atmospheric conditions when these were explicitly mentioned. It was assumed, for example, that aurora visible in twilight or bright moonlight could not be very faint. For comparison with the magnetic phenomena it was necessary to employ Greenwich time, and to have hourly auroral character figures. On nights of bright aurora there were often several observations in the course of an hour. The auroral character accepted for the hour was the highest assigned to any observation during the hour. Any hour on which one or more observations had failed to detect any aurora, under ordinarily favourable atmospheric conditions, was assigned the character 0·0. Hours during which no observation had been taken were disregarded.

The hours with character 0·0—i.e., the hours when no aurora was detected under conditions affording a reasonable chance of its being seen—formed $32\frac{1}{2}$ per cent. of the whole. This implies that $67\frac{1}{2}$ per cent. of the hours which I had accepted as affording a reasonable chance of faint aurora being seen showed aurora. When assigning character figures I had only the auroral log to guide me. In his published volume* the conclusion reached by Sir Douglas Mawson himself is as follows : " On 52 per cent. of all hours of moderate twilight and darkness, and including all moonlight hours, when the sky was clear for observation, auroral lights would be seen at least sometime within the hour." Sir Douglas used local time, and included four months which I omitted, as unprovided with corresponding magnetic data. But the difference between us seems mainly due to my omitting a number of complete nights of bright moonlight, or other unfavourable conditions when no aurora was recorded. It seemed unnecessary to repeat my calculations, as the omission of entire nights of bright moonlight could hardly affect the diurnal variation, or prejudice any other object which I had in view.

§ 3.

Since little attention has been given to the question of a numerical criterion of magnetic disturbance for shorter intervals, we naturally turn for guidance to suggestions made for the day.† For it we have in the first place the well-known international scheme : 0 (quiet), 1 (moderately disturbed), 2 (highly disturbed). Various criteria have been proposed involving the first power of the daily range of one or more of the magnetic elements. Use has actually been made of $\triangle D$ and $\triangle H$, the declination (D) and horizontal force (H) absolute daily ranges. A variant is Dr. Bauer's proposal, $H\triangle H$, or the more complete $H\triangle H+V\triangle V$, where V denotes vertical force. Then, based on Bidlingmaier's " magnetic activity," a quantity involving squares of departures from the normal, we have the sum of the squares of the absolute ranges of three rectangular components, or the sum of the squares of all the hourly ranges throughout the day. At a fixed station H and V, when used as multipliers of $\triangle H$ and $\triangle V$, may be treated as constants. Also it is fairly obvious that any reasoning which supports $H\triangle H$ as a criterion of disturbance must equally support $V\triangle V$. At a station near the magnetic equator $V\triangle V$ may be regarded as negligible compared with $H\triangle H$, but at Cape Denison, where V was roughly 20 times H, it is the other way about. The use of the squares of hourly ranges as a criterion for the day's disturbance suggests for the hour the squares of 5-minute, if not 2·5 minute, intervals. But the labour this would have entailed did not seem justified. There was also an obstacle to hourly D ranges. In view of the large D ranges encountered, the D magnetograph at Cape Denison was hypersensitive. In the course of a disturbed day use had to be made now of the one, now of the other, of the traces supplied by the two mirrors carried by the magnet. This would have added materially to the trouble of measuring hourly ranges during active disturbance.

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* Records of the Aurora Polaris, p. 144

† See Gerland's Beiträge zur Geophysik, Bd. XV, p. 14 (1926).

It seemed desirable, as a preliminary, to try criteria of three kinds, one employing the scale 0, 1, 2 applied to each hour, as first suggested by Bidlingmaier, a second kind employing the first power of the absolute range, and the third kind the second power. It seemed unnecessary to employ D, as it seemed unlikely to differ much from H, but it appeared desirable to consider H and V ranges separately. Their subsequent combination, if such appeared desirable, would present no difficulty.

§ 4.

A remark applicable to any criterion involving only the ranges during the included interval of time, whether a day or an hour, is that it cannot directly measure *disturbance,* inasmuch as it contains a contribution from the regular diurnal inequality, which does not vanish on the quietest of days. All the criterion can do is to wax and wane with disturbance, but for our present purpose that is all we want.

The problem presented by the hour has one difficulty, which, though not wholly special to it, is shared to only a minor extent by the day at an ordinary station. Owing to the annual variation in the daily changes, days at the beginning and end of a month will naturally, quite apart from disturbance, differ in their daily ranges. This difference is, however, comparatively small, at least in most months. Relatively considered, it is trifling compared with the differences in the contributions made by the regular diurnal variation to the different hours of the day.

At an English station, if we accepted the hourly range as our criterion, the resulting diurnal variation would hardly merit acceptance as a register of *disturbance.* But Cape Denison, fortunately for our immediate purpose, was not an ordinary station. In June, 1912, the month we intend to use for the preliminary inquiry, the average range within the hour was $24{\cdot}7\gamma$ in H and $29{\cdot}3\gamma$ in V, while the average hourly changes arising from the regular diurnal variation were respectively only $2{\cdot}4\gamma$ and $4{\cdot}4\gamma$. The intervals, moreover, between the highest and lowest values of the element within the hour were more nearly 30 than 60 minutes. Thus the influence of the regular diurnal inequality on the hourly range was even less than might appear at first sight. In neglecting it we introduce no larger uncertainty than we should do in assuming equally disturbed March days in England to have equal daily ranges.

Another point to be remembered is that naturally 30 days contribute to each hourly value. Thus, the parallel case is not the derivation of the disturbance of a single day from the range at a single station, but the derivation of the average disturbance of a month at a particular station from the ranges of 30 days, or the derivation of the disturbance during an individual day from the ranges at 30 stations.

§ 5.

The results of the preliminary investigation, confined to June, 1912—as being one of the chief auroral months—are given in Table I. The columns are numbered at the foot for facility of reference. Local time was really 9 hours 29 minutes fast on Greenwich time. Thus, the 60 minutes ending at 1 hour G.M.T. really centred at 9 hours 59 minutes L.M.T. This is given in the table as 10 hours, as near enough for practical purposes. It was convenient to have the means of seeing at a glance what were day and night hours. The absolute maximum and minimum in each column are distinguished by heavy type.

Table I.—*Results from Various Criteria of Disturbance at Cape Denison, June, 1912.*

Hour G.M.T. ending at	Hour L.M.T. centring at	Squares of hourly ranges.				Hourly ranges.		Character Percentages.		
		From 30 days.		From 29 days.		All days.		Mean.	Numbers of	
		H	*V*	*H*	*V*	*H*	*V*		2's	0's
Hour.	Hour.									
1	10	72	51	114	75	109	95	116	130	46
2	11	104	143	147	187	129	154	**135**	**193**	46
3	12	98	190	166	**278**	132	**175**	126	130	30
4	13	133	166	**223**	195	**146**	150	**135**	155	**0**
5	14	94	74	147	92	130	104	116	142	61
6	15	96	50	108	64	117	86	119	104	30
7	16	51	43	78	38	90	70	86	78	137
8	17	62	30	87	35	89	63	84	65	137
9	18	24	**14**	30	**14**	58	**45**	**57**	39	**213**
10	19	36	39	55	46	70	64	70	65	198
11	20	49	51	50	34	74	67	71	65	198
12	21	**366**	179	102	156	121	113	84	104	182
13	22	276	252	132	184	134	140	99	117	121
14	23	327	**293**	160	180	134	150	106	129	106
15	24	136	243	142	189	117	141	113	168	121
16	1	144	200	135	160	112	132	96	104	137
17	2	**13**	21	**22**	33	**48**	59	65	**0**	152
18	3	20	29	29	39	56	66	70	52	182
19	4	19	66	30	51	56	79	83	53	121
20	5	32	49	39	60	64	79	103	91	61
21	6	49	52	78	66	89	85	106	91	61
22	7	63	40	105	60	106	83	116	91	15
23	8	67	75	107	88	109	107	128	130	15
24	9	69	50	114	76	110	93	116	104	30
Column	number	1	2	3	4	5	6	7	8	9

Columns 1 and 2 take the square of the hourly range as the criterion of disturbance; they refer respectively to *H* and *V*. The figures are percentages of $1{,}530\gamma^2$ and of $2{,}178\gamma^2$, the respective means of the 30×24 absolute values. Columns 3 and 4 differ from columns 1 and 2 only in neglecting the one largest range in each hour of the day. The means from the 29×24 data remaining were reduced to $777\gamma^2$ for *H*, and $1{,}221\gamma^2$ for *V*. Columns 5 and 6 use the first power of the hourly range as a criterion, employing all days of the month. The figures are percentages of the means $24{\cdot}7\gamma$ and $29{\cdot}3\gamma$ chronicled above. Column 7 gives the mean of the character figures 0, 1 and 2 applied, treated as numerical quantities. The adjudication was made on the general appearance of the traces, especially the H and V traces, no regard being paid to the range. The figures are percentages of 1·04, the mean of all the hourly character figures assigned. The numbers of 2's and 0's in columns 8 and 9 are also percentages. The 2's assigned during all hours of June numbered 185, the 0's numbered 158.

We should obviously have got smoother values if we had combined H and V ranges in one criterion, but Table I has the advantage of showing that the two elements are in good general agreement. A phenomenon, however, which makes even greater appeal to the eye is the difference between columns 1 and 2, on the one hand and columns 3 and 4 on the other. The exclusion of but 1 out of the 30 data available for each hour of the day has profoundly altered the diurnal variation. Columns 1 to 4 all show a conspicuous double oscillation, with maxima in the early (Greenwich) morning and afternoon respectively ; but columns 1 and 2 put the principal maximum in the afternoon, while columns 3 and 4 put it in the morning. Somewhat curiously, the position of the principal minimum is not affected. Columns 1 and 3 agree in putting it in the hour ending at 17 hours G.M.T., while columns 2 and 4 put it in the hour ending at 9 hours. What appears as the principal minimum in H appears, however, as a secondary minimum in V, and conversely, and the apparent difference between the two minima is trifling. Thus the difference between the two elements is not important, and may be accidental.

§ 6.

Before discussing Table I further, it is desirable to see more clearly how the difference between the first and second pairs of columns is brought about. To this end we give in Table II the hourly ranges whose exclusion from the five hours of the early Greenwich afternoon is mainly responsible for the difference. The table shows for comparison the corresponding means from all the June days for the five hours in question.

TABLE II.—*Hourly Ranges on Special Dates, June,* 1912.

Hour G.M.T. ending at	Special dates.	Ranges on special dates.		Mean ranges from all days.	
		H	V	H	V
Hour.		γ	γ	γ	γ
12	1st	381	248	30	33
13	9th	311	315	33	41
14	8th	338	358	33	44
15	9th & 8th	175	303	29	41
16	9th	189	272	28	39

It will be seen that the first three H ranges in Table II are each from 9 to fully 12 times the average range, while the five V ranges are each from 7 to 9 times the average. These 8 hours are each the equivalent of from 50 to 150 average hours, when our criterion is the square of the hourly range, and the equivalent of from 7 to 12 average hours when our criterion is the first power of the range. As it so happened, the more outstanding June ranges fell in different (Greenwich) hours, but this may have been a pure accident. Also the hourly ranges in Table II, large as they are, were exceeded on other occasions. On July 6, 1912, H had ranges of 498γ and 500γ in two successive hours. Such a day would exert as much influence for the special hour concerned as 400 ordinary days, when our criterion is the square of the range, or as 20 ordinary days when our criterion is the first power. The shorter the period we are considering the greater the effect of such windfalls. The complete range 311γ in H in the hour ending at 13 hours on June 9 was the range for the whole day as well as for the hour, but the maximum and minimum occurred within 5 minutes of one another. If we took 5 minutes as our unit of time, instead of the hour, the influence of such an incident would be simply enormous.

It may appear at first sight that the possibility that the omission of one out of thirty observations may produce an enormous effect is sufficient to condemn the use of the square of the range as a criterion of disturbance. A little reflection, however, will show that this is not a rational conclusion. Take the simpler case of rainfall. A single hour of thunderstorm in a dry month may produce as much rain as the rest of the month. The inclusion of that hour will make an astonishing difference to the diurnal variation of the month. But that implies no fault in the way of measuring rain. For the purposes of the mechanical or electrical engineer, if he can store all that falls, the thunderstorm inch is just as good as any other inch. What it does mean, however, is that a really representative diurnal variation of rainfall requires a very long series of observations. Similarly, if we adopt the square of the hourly range as a criterion, we cannot be certain at a station like Cape Denison of getting a really representative diurnal variation for any month of the year, unless we have a large number of years' observations at our disposal. The same remark applies, though to a lesser extent, to the first power of the hourly range as a criterion.

In addition to these considerations there is the fact that the scale 0, 1, 2 is much more analogous than the other criteria to the auroral criterion adopted, and we shall accordingly, in what follows, give it the preference. It is well, however, to consider the number of 2's and 0's as well as the mean character figure. It is, for example, desirable to know whether a mean character figure 1·0 represents a dead level of mediocrity, or a mixed assemblage of 0's, 1's and 2's.

§ 7.

Returning to Table I, it will be seen that the mean character figure and the number of 2's agree with the results in columns 3 to 6 in placing the principal maximum of disturbance in the early (Greenwich) morning ; but they also show a very substantial secondary maximum in the early (Greenwich) afternoon. The mean character figure and the number of 0's agree with the V range criteria in putting the principal minimum of disturbance in the hour ending at 9 hours G.M.T., while the number of 2's agrees with the H range criteria in putting the principal minimum in the hour ending at 17 hours G.M.T.

A good deal of accident must enter into the results from a single month, and in dealing so fully as we have done with June, 1912, our principal object has been to bring out the nature of the several criteria, the extent to which they agree, and the reason why in our subsequent work principal use is made of the scale 0, 1, 2.

§ 8.

The main object of Table III is the investigation of a point of great physical interest. Ordinary meteorological elements like temperature follow local time. That is also true of certain magnetic phenomena, as, for example, the diurnal inequality on the international quiet days. But what happens in the case of magnetic disturbance? We have magnetic storms simultaneously in progress everywhere, and "sudden commencements" occur apparently at the same time—to a minute, if not to a second—the whole world over. It is at least conceivable that the diurnal variation of magnetic disturbance should follow Greenwich (or universal) time everywhere. The results obtained from magnetic disturbance during 1911 and 1912 at Cape Evans*—the base station of the British Antarctic Expedition—showed an unexpected resemblance to those at Eskdalemuir, when Greenwich time was employed throughout. It thus became of the utmost importance to know how the diurnal variation of disturbance at Cape Denison compared with that at Cape Evans. The geographical positions of the two stations are: Cape Evans, 77° 38′ S., 166° 24′ E., Cape Denison, 67° 0′ S., 142° 40′ E. According to the calculations of Mr. E. N. Webb, the magnetic observer at Cape Denison, the approximate position of the South magnetic pole in 1912 was 71° 10′ S., 150° 45′ E. According to these figures the magnetic pole lay not far from the direct line between the two stations, its distance from Cape Denison being only about two-thirds of its distance from Cape Evans. The difference of longitude between the two stations, 23° 44′, means a difference of 1 hour 35 minutes in local time, midnight coming first at Cape Evans.

TABLE III.—*Diurnal Variation of Magnetic Disturbance at Cape Denison, Cape Evans, and Eskdalemuir.*

Hour G.M.T. ending at	Mean hourly character.			Percentage numbers.					
				2's			0's		
	C.D.	C.E.	E.	C.D.	C.E.	E.	C.D.	C.E.	E.
Hour									
1	1·34	1·05	0·65	202	104	167	29	66	95
2	**1.44**	1·02	0·57	**229**	111	123	**15**	83	104
3	1·43	0·97	0·49	222	91	92	16	89	118
4	1·40	0·90	0·45	215	82	89	22	118	124
5	1·26	0·89	0·41	167	74	61	31	115	129
6	1·07	0·87	0·40	107	80	48	56	128	129
7	0·82	0·84	0·43	52	71	41	101	129	124
8	0·69	0·81	0·45	38	**67**	48	133	137	118
9	**0.58**	0·78	0·39	**27**	71	54	161	166	133
10	0·59	0·80	**0.33**	42	90	**14**	168	168	**139**
11	**0.58**	**0.77**	0·46	45	82	20	176	**169**	114
12	0·59	0·80	0·59	56	80	51	**180**	151	92
13	0·70	0·83	0·65	56	80	65	143	146	80
14	0·77	0·89	0·66	68	91	85	127	120	81
15	0·70	0·89	0·72	60	79	129	145	113	75
16	0·60	0·94	**0.73**	45	80	119	168	83	**70**
17	0·59	0·96	**0.73**	34	75	146	164	81	74
18	0·62	1·03	0·72	39	91	129	157	64	75
19	0·73	1·15	0·70	47	123	129	127	50	79
20	0·85	1·20	0·68	69	141	143	101	41	85
21	0·98	1·27	0·70	103	160	**201**	83	**34**	88
22	1·16	**1.28**	0·67	136	**177**	160	43	38	90
23	1·25	1·21	0·62	152	165	126	27	50	95
24	1·32	1·14	0·67	189	142	160	27	57	89
Column	1	2	3	4	5	6	7	8	9

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* British Antarctic Expedition, 1910-1913. Terrestrial Magnetism, pp. 142 et seq.

Table III gives three sets of comparative results for Cape Denison (C.D.), Cape Evans (C.E.) and Eskdalemuir (E). These are based respectively on the mean character figure (columns 1 to 3), the number of 2's (columns 4 to 6) and the number of 0's (columns 7 to 9). The principal maximum and minimum in each case are in heavy type. The C.D. and E. results are from the same 15 months of 1912 and 1913. The C.E. results, based on 1911 and 1912, refer to the year as a whole. In the original comparison the data employed for Eskdalemuir synchronised with those used for Cape Evans, but they agreed in all essential features with those now given. The point that chiefly impressed me when comparing Cape Evans and Eskdalemuir was the approximate agreement between the times when 2's were most numerous and the times when 0's were most numerous.

There is one feature in which there is at least an approach to agreement between the three stations—viz., a slackening of disturbance in the later part of the (Greenwich) forenoon. The principal minima in the first three columns occur between 9 hours and 11 hours, the principal minima in columns 4 to 6 occur between 8 hours and 10 hours, and the principal maxima in columns 7 to 9 occur between 10 hours and 12 hours. There is, however, a prominent difference between the stations even in the matter of the minima of disturbance. The mean character figure at Cape Denison (column 1) shows a secondary minimum in the hour ending at 17 hours, which falls little short of the principal minimum. Column 4 agrees in putting a prominent secondary minimum at the same hour, and column 7 shows a prominent maximum only an hour earlier. Thus all the Cape Denison criteria agree in putting a very decided if secondary minimum of disturbance between 16 hours and 17 hours G.M.T. There is no trace of such a minimum at Eskdalemuir, nor is there in the Cape Evans columns 2 and 8. In column 5, however, there is a slight suggestion of a minimum.

Coming now to the maxima: At Cape Denison the three criteria agree in indicating a principal maximum of disturbance in the hour ending at 2 hours G.M.T. At Cape Evans columns 2 and 5 show a principal maximum in the hour ending at 22 hours G.M.T., and column 8 shows a principal minimum of 0's one hour earlier. Thus here again the criteria are in practical agreement, and put the principal maximum of disturbance some 4 hours earlier than at Cape Denison.

At Eskdalemuir the criteria are less accordant. As appears from column 6, the maximum number of 2's appears in the hour ending at 21 hours G.M.T.—i.e., only an hour earlier than at Cape Evans. According, however, to columns 3 and 9, the mean character figure has its principal maximum and the number of 0's its minimum at 16 hours or 17 hours G.M.T. This, in fact, is an excellent example of the advisability of inquiring how the mean character figure is made up. Its high value at Eskdalemuir at 16 hours and 17 hours is due not so much to the presence of active disturbance as to the absence of quiet conditions. It will be seen that the variations in the mean character figure at Eskdalemuir during the afternoon are not large. The tendency to increase in the number of 2's is attended by a tendency to increase in the number of 0's.

In addition to the principal maximum there is, according to columns 1 and 4, a quite decided secondary maximum of disturbance at Cape Denison in the hour ending at 14 hours G.M.T. There is no suggestion of a maximum at this hour at Eskdalemuir, nor is there in the case of the mean character figure at Cape Evans.

Column 5, however, is not unfavourable to a trifling secondary maximum in the number of 2's.

One or two years' observations near sunspot minimum cannot be relied on to supply results which are closely representative in every detail of all years. But the results obtained for Eskdalemuir from 1911 to 1912, and again from 1912 to 1913, derive support from results obtained for Kew by Mr. J. M. Stagg* for the 11 years 1913-23, following a similar procedure. For the 11 years as a whole he found the number of 2's to have its greatest and least values in the hours ending at 22 hours and 11 hours respectively—i.e., an hour later than in Table III. But for sunspot minimum years he found the maximum in the hour ending at 21 hours. His figures also agree in showing no certain secondary maximum or minimum in the diurnal variation. Kew is a much less naturally disturbed station than Eskdalemuir. Also during the years considered by Mr. Stagg it suffered increasingly from electric trains, but that ought not to prejudice the estimate of hours of character 2.

§ 9.

The outstanding result in Table III, the difference in the hours of the principal maximum of disturbance at the three stations, appeared so important that a further investigation was made on somewhat different lines. The results appear in Tables IV and V. Table IV is confined to the 7 complete months April to October and the first

TABLE IV.—*Diurnal Variations of Magnetic Disturbance at Cape Denison and Cape Evans, April to November, 1912.*

Cape Denison	0			1			2			0			1			2			Cape Evans
Cape Evans	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	Cape Denison
1 h. to 6 h.	88	12	0	47	51	2	4	67	29	15	79	6	1	46	53	0	8	92	1 h. to 6 h.
1 h. to 24 h.	64	35	1	27	65	8	3	54	43	57	41	2	18	58	24	1	28	71	1 h. to 24 h.
16 h. to 21 h.	52	47	1	10	76	14	1	46	53	81	18	1	30	58	12	3	44	53	16 h. to 21 h.
Column	1*a*	2*a*	3*a*	4*a*	5*a*	6*a*	7*a*	8*a*	9*a*	1*b*	2*b*	3*b*	4*b*	5*b*	6*b*	7*b*	8*b*	9*b*	Column

TABLE V.—*Diurnal Variations of Magnetic Disturbance at Cape Denison and Eskdalemuir, January to July, 1913.*

Cape Denison	0			1			2			0			1			2			Eskdalemuir
Eskdalemuir	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	Cape Denison
1 h. to 6 h.	86	14	0	65	32	3	33	55	12	18	62	20	5	46	49	0	30	70	1 h. to 6 h.
1 h. to 24 h.	71	29	0	46	49	5	25	57	18	46	46	8	21	57	22	3	41	56	1 h. to 24 h.
13 h. to 18 h.	58	41	1	27	67	6	4	67	29	18	82	0	35	53	12	8	46	46	13 h. to 18 h.
Column	1*a*	2*a*	3*a*	4*a*	5*a*	6*a*	7*a*	8*a*	9*a*	1*b*	2*b*	3*b*	4*b*	5*b*	6*b*	7*b*	8*b*	9*b*	Column

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* Meteorological Office Geophysical Memoirs, No. 32, p. 13.

part of November, 1912, for which absolutely synchronous data were available from Cape Denison and Cape Evans. In the first nine columns, 1*a* to 9*a*, the Cape Denison hourly character figures 0, 1, 2 are the guiding ones. It was found how often character 0 at Cape Denison was associated with characters 0, 1, 2 respectively at Cape Evans. Taking, for example, the whole 24 hours, there were 1,462 hours of character 0 at Cape Denison. Of these hours, 935 (or 64·0 per cent.) got character 0 at Cape Evans, 517 (or 35·4 per cent.) got character 1, and 10 (or 0·7 per cent.) got character 2. These percentages, 64, 35 and 1 to the nearest unit, appear in the first three columns, 1*a* to 3*a*, in the line devoted to the whole 24 hours. The other percentage figures in columns 1*a* to 9*a* were arrived at in a precisely similar way. For the second half of the table, columns 1*b* to 9*b*, the Cape Evans characters were treated as fundamental. Of the 1,653 hours awarded character 0 at Cape Evans, 935 (56·6 per cent.) obtained 0 at Cape Denison, 686 (41·5 per cent.) obtained 1, and 32 (1·9 per cent.) obtained 2. These percentages taken as 57, 41 and 2 appear in columns 1*b*, 2*b* and 3*b*. Out of the 5,252 hours employed in Table IV, 1,462 got 0's and 1,258 got 2's at Cape Denison, while 1,653 got 0's and 765 got 2's at Cape Evans. The Cape Denison magnetographs were on the whole decidedly the more sensitive, and with greater sensitiveness the tendency seems to be to give fewer 0's and more 2's. Again, at Cape Evans the standard was largely determined by 1911, which was a decidedly less quiet year than 1912. Thus the difference between the numbers of 0's and 2's at the two stations does not necessarily mean that Cape Denison was the more disturbed. As the totals of 0's and 2's are not the same at the two stations, we should not expect absolute identity between the corresponding figures in corresponding columns of Table IV, even if the diurnal variations of disturbance were identical, but we should expect parallelism between the changes shown as we pass from one column to the next of the same group, or from one line to the next. Now this is exactly what we do not get. For example, as we pass from line 1 to line 3 the figures in column 1*a* go down from 88 to 52, and the figures in column 2*a* go up from 12 to 47, while the figures in column 1*b* go up, and the figures in column 2*b* go down. In short, all the data in Table IV support the view that at Cape Denison the six hours ending at 6 hours G.M.T. were more disturbed, and the six hours ending at 21 hours G.M.T. were less disturbed than the average, whereas at Cape Evans it was exactly the other way about. Of course, the hours in Table IV were specially selected with a view to emphasising the difference between the two stations. In the first instance the 24 hours were considered individually, and then arranged in groups, first of 3, then of 6. The three hours ending at 21 hours G.M.T. were those in which Cape Evans *relatively considered* was most disturbed, and the three hours ending at 6 G.M.T. were those in which the pre-eminence of Cape Denison disturbance was greatest.

Table V, constructed on exactly similar lines, and also confined to seven months, January to July, 1913, compares Cape Denison and Eskdalemuir. In spite of the great disparity in the distribution of the character figures, 2's being scarce at Eskdalemuir, the evidence that the diurnal variation referred to Greenwich time is widely different at the two stations is overwhelming. The pre-eminence of Cape Denison is conspicuous in the same group of hours as when the comparison was between it and Cape Evans. But the hours when Eskdalemuir, *relatively considered,* comes to the front occur earlier in the Greenwich day than those in which Cape Evans was pre-eminent.

The fact that the diurnal variations of disturbance should differ more at Cape Denison and Cape Evans, stations differing by less than 11° of latitude and 24° of longitude, than they do at Cape Evans and Eskdalemuir, stations separated by nearly 133° of latitude and 170° of longitude, appears most surprising, at least at first sight. A possible explanation would be obvious if the 12-hour wave were dominant in disturbance ; but at Eskdalemuir, especially, there is little trace of a 12-hour wave.

§ 10.

The fact that the hours of the day when disturbance is most active are not the same at two stations does not mean that conditions tend to be quiet at the one station when disturbed at the other. The reverse is the case. Out of the whole 5,252 hours on which Table IV is based there were only 32 when character 2 at Cape Denison was synchronous with character 0 at Cape Evans, and only 10 when character 0 at Cape Denison was synchronous with character 2 at Cape Evans. Disturbance was so very much more in evidence at Cape Denison than at Eskdalemuir that associations of character 2 at the former station with character 0 at the latter were not uncommon ; but there were only 8 hours when character 0 at Cape Denison was synchronous with character 2 at Eskdalemuir. In the majority, moreover, of these exceptional cases the 2's and 0's were rather on the borderland of 1's. Supposing disturbance gradually to increase after a decidedly quiet time, we inevitably have a series of 0's followed by a series of 1's, and that by a series of 2's. But the hour at which the transition is made from 0 to 1, or from 1 to 2, is largely a matter of accident. That no doubt played some part in a good many of the exceptional cases just referred to, but on the whole they represented a very decided difference between the disturbance conditions at the two stations. This should be clear on inspection of Table VI, which gives the mean values of the ranges from the special occasions at the pairs of stations. The force equivalent is given for the D range at Cape Denison. The components E′, N′ at Cape Evans were directed about 7·5° south of east and east of north. There were no vertical force data from Eskdalemuir for 1913. Disturbance, as a rule, was so enormously greater at Cape Denison than at Eskdalemuir that it was almost a surprise to find that there were hours in which magnetic changes were actually greater at Eskdalemuir than at Cape Denison.

TABLE VI.—*Mean Hourly Ranges from Special Occasions.*

Occasions ...	32		10		8	
Character ...	2 at C.D., 0 at C.E.		0 at C.D., 2 at C.E.		0 at C.D., 2 at E.	
	At C.D.	At C.E.	At C.D.	At C.E.	At C.D.	At E.
	γ	γ	γ	γ	γ	γ
	D 32	E′ 14	D 24	E′ 52	D 15	N 28
	H 38	N′ 12	H 15	N′ 37	H 7	W 18
	V 38	V 7	V 14	V 24	V 10	...

§ 11.

Table VII is devoted to the question of the parallelism between the diurnal variations in aurora and in magnetic disturbance. Column 1 shows the distribution throughout the day of the 250 hours to which I had allotted auroral characters of 2·0 or 1·5, the significance of which has been already explained. Column 2 gives the distribution of 180 hours when aurora was in the zenith. Column 3 gives the mean hourly magnetic character figure at Cape Denison derived from the four winter months (W.) May to August, during which aurora was principally seen. Column 4 does the same for the summer months (S.), November, January and February, when no occurrence of aurora was noted.* Columns 5 and 6 give the distribution of magnetic character 2 for winter and summer, and columns 7 and 8 deal similarly with the 0's. The figures in columns 5 to 8 are percentages of the respective

TABLE VII.—*Diurnal Variation of Aurora and Magnetic Disturbance at Cape Denison.*

Time.		Auroral occurencies.		Magnetic disturbance.					
Hour G.M.T. ending at	Hour L.M.T. centring at	Bright aurora.	Zenithal aurora.	Mean character.		Percentages.			
						2's		0's	
				W	S	W	S	W	S
Hour.	Hour.								
1	10			1·02	1·82	139	219	44	0
2	11			**1.19**	1·80	**215**	213	**24**	0
3	12			1·15	**1.83**	184	**219**	26	0
4	13			1·11	1·82	177	216	34	0
5	14			1·04	1·61	160	161	45	8
6	15			0·84	1·51	101	137	79	16
7	16	1	3	0·59	1·25	52	73	124	25
8	17	6	3	0·50	1·02	56	43	150	90
9	18	10	4	**0.43**	0·93	38	33	160	139
10	19	11	1	0·47	0·91	52	39	155	172
11	20	19	2	0·50	**0.72**	56	**24**	151	262
12	21	25	4	0·50	0·73	83	33	**161**	**278**
13	22	**38**	2	0·64	0·79	90	39	124	254
14	23	37	6	0·72	0·90	108	49	111	205
15	24	19	3	0·71	0·85	115	43	117	221
16	1	19	2	0·58	0·80	76	30	138	221
17	2	7	5	0·49	0·86	**35**	30	145	180
18	3	7	11	0·49	0·91	45	33	146	156
19	4	10	24	0·59	1·01	63	33	127	82
20	5	12	32	0·70	1·19	76	73	105	57
21	6	20	**40**	0·80	1·37	111	112	91	33
22	7	7	30	0·92	1·60	118	161	62	0
23	8	2	8	1·02	1·67	118	179	38	0
24	9			1·02	1·77	132	207	41	0
Means	..			0·75	1·24				
Column	...	1	2	3	4	5	6	7	8

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* December *H* and *V* records at Cape Denison were lacking or unsatisfactory.

means. Principal maxima and minima in columns 3 to 8 are in heavy type. Among Sir Douglas Mawson's deductions were the following :—

" Our experience at Cape Denison very conclusively indicated that the daily period of apparently most intense auroræ was between 9 p.m. and 11.30 p.m." (i.e., between 21 hours and 23·5 hours L.M.T.) (l.c., p. 158), and again, speaking of zenithal aurora, " The most obvious feature is the extreme frequency of zenith aurora in the early morning hours immediately preceding daylight " (l.c., p. 168). Table VII is in excellent agreement with these statements. Sir Douglas counted as zenithal any aurora within 20° of the zenith, and he employed several months which are not included in Table VII owing to the lack of corresponding magnetic data. This explains his greater number (272) of zenithal occurrences. In addition to a principal maximum frequency of bright aurora about 13 hours G.M.T. (or 22½ hours L.M.T.), column 1 shows a secondary maximum at 6 hours L.M.T., synchronous with the maximum frequency of zenithal auroras in column 2.

Taking the magnetic data for winter (W.) in Table VII as the more appropriate, it will be seen that the principal maximum of bright aurora is nearly coincident with a secondary maximum in the mean magnetic character figure and the number of 2's, and with a secondary minimum in the number of 0's. Also the minimum at about 17 hours G.M.T. in the frequency of bright aurora is fairly coincident with the principal minimum in magnetic 2's, and with a secondary maximum in the number of magnetic 0's. There is thus a very sensible parallelism between some of the phenomena in the diurnal variations of aurora and magnetic disturbance. But what appears at first sight a complete disagreement is the occurrence of the principal maximum of magnetic disturbance at 11 hours L.M.T., an hour when aurora never was and never could be seen. A possible explanation, however, at once suggests itself. The figures in Table VII indicate at first sight a rapid decline after 6 hours L.M.T., both in bright and zenithal aurora. But this may well have been wholly due to the effects of increasing daylight. In the midwinter months, June and July, aurora was occasionally seen as early as 16 hours L.M.T., and as late as 8 hours L.M.T., but even in May and August 16 hours and 8 hours became impossible, and in the equinoctial months the limits were much narrower. In Sir Douglas Mawson's words, " The rapid decrease (of auroral occurrences) at the limits is . . . to be ascribed to increasing twilight obscuring weaker effects, and it seems probable that were the darker hours of longer duration the rise of the curve (showing mid-winter auroral frequency) would continue on either hand instead of reversing " (l.c., p. 166). If we assume that the overhead electrical phenomena, seen as aurora at night, may exist during the day though invisible, it is at least possible that the increase in frequency of the electrical storms did not really stop at 6 hours L.M.T., but went on right up to the time of the principal maximum of magnetic disturbance about 11 hours L.M.T.

The resuscitation of brilliant aurora in the early morning L.M.T. shown in column 1 of Table VII is probably underestimated, owing to the effects of daylight ; but in Sir Douglas Mawson's opinion the brightest auroras did have their maximum at the time suggested by the table. " The auroræ so regularly appearing in the twilight hours of early morning . . . though never extremely brilliant to look at, must often have been intense in order to be at all apparent in twilight. But . . . it would appear that, after all, the later evening hours were *par excellence* the period of the day when auroræ of the greatest intensity were to be expected " (l.c., p. 159).

Before leaving Table VII it is well to compare the winter and summer magnetic results. The chief difference between the mean character results in columns 3 and 4 is that, absolutely considered, the summer values were much the higher. This was equally true of character figures for the day. The winter months, the principal months for aurora, were on the whole much the quietest months magnetically. The summer months, when no aurora was seen, were much the most disturbed months. In both respects the equinoctial months took an intermediate place. We see in both columns 3 and 4 a principal maximum in the late (local) forenoon, a secondary maximum an hour or two before midnight. As regards the number of 2's, winter and summer, columns 5 and 6, again agree in showing a principal maximum a little before (local) noon, and a secondary maximum a little before midnight ; but this secondary maximum is less prominent in summer than in winter. In both seasons there are two minima almost equally conspicuous ; they are separated by only about 8 hours in winter and less in summer.

As regards 0's, columns 7 and 8, the two seasons agree in placing the principal maximum at or a little before 21 hours L.M.T., near the time of a minimum in 2's. In winter there is a secondary and not very much inferior maximum between 2 hours and 3 hours L.M.T., near the time of the minimum in bright aurora. In summer not a single 0 was attached to any hour between 21 hours and 4 hours G.M.T. ($6\frac{1}{2}$ hours to $13\frac{1}{2}$ hours L.M.T.). It is possible that if a very much higher standard of disturbance had been accepted for summer, so as to produce a large increase in the number of 0's, a double daily oscillation might have been clearly recognised in that season as well as in winter. There is a suggestion of a minimum at 23 hours L.M.T. in column 8, synchronous with the secondary maximum in column 6. However this may be, it seems indisputable that the main features of the diurnal variation of magnetic disturbance are the same for summer, the season of no auroras, as for winter, the season when auroras are at their maximum.

§ 12.

Table VIII compares the night and day phenomena in a different and more detailed way. It uses the results of twelve months, March to October, 1912, and April to July, 1913. Any (Greenwich) hour in which there was even one aurora seen in the course of a month was regarded as an hour when aurora, if existent,

TABLE VIII.—*Magnetic Disturbance, Night Hours and Day Hours, at Cape Denison.*

Month.	Hours per diem. Aurora		2's in hours when Aurora		Expectation of a 2 in hours when Aurora	
	Visible.	Invisible.	Visible.	Invisible.	Visible.	Invisible.
March, 1912	5	19	17	141	52	113
April, 1912 & 1913 ...	14	10	85	204	50	169
May, 1912 & 1913 ...	15	9	92	111	73	146
June, 1912 & 1913 ...	17	7	122	80	85	136
July, 1912 & 1913 ...	17	7	101	67	85	137
August, 1912	16	8	37	81	47	205
September, 1912 ...	12	12	16	98	28	171
October, 1912 ...	5	19	24	234	44	115
Totals			494	1,016		

could be seen during the whole month. In months like April and October the length of the day is altering somewhat rapidly, and failure to see the aurora in a particular hour of the day is not incompatible with the possibility of seeing it during that hour during a small part of the month. But for our present object meticulous accuracy is not called for.

In the expectation figures in Table VIII, 100 is taken to represent the chance which the average hour of the month has to get magnetic character 2. According to the table, during every month of the year when aurora was recorded, the part of the day when aurora was seen was much quieter than the part of the day when it was not seen. The greater prominence of magnetic disturbance in the daylight hours, though reduced, is still decided in June and July, which were the months when aurora was most pronounced. These two months included 14 out of the 28 occasions specified by Sir Douglas Mawson (l.c., p. 149) as being those when colour effects were most brilliant.

It is well, however, to bear in mind the fact that these conclusions depend on the magnetic character criterion which we have decided to employ. It is by no means certain that we should have reached the same conclusion for the winter months, or at least for June and July, if we had employed a criterion such as the square of the hourly range. In fact, if we did employ as our criterion of magnetic disturbance the sums of the squares of the hourly H and V ranges, our conclusion would be that in June, 1912, the night as a whole was almost equally disturbed with the day. There were only 13 hours during June which had H hourly ranges exceeding 100γ, and the range next largest to the 5 specified in Table II was only 140γ. Thus in June, whether accidentally or not, the night hours contained all the more outstanding disturbances in H, and the same was true to a nearly equal extent of V. Most of these outstanding occasions were certainly accompanied by brilliant aurora ; but this is uncertain as regards the largest of the H ranges, which occurred on June 1. At Cape Denison the sky was overcast during the whole night. At the "Grottoes," the station occupied by the Australian Antarctic Expedition in Queen Mary Land (66° 20′ S., 95° 2′ E.), an aurora "with faint colouring" was reported on June 1, but the time of occurrence is not given. The Cape Evans record, which I was able to examine thanks to the courtesy of Captain C. S. Wright, stated that on the night in question there was clear strong moonlight and no aurora. Under the circumstances specified, however, faint aurora might have escaped detection. Also, as a matter of fact, simultaneous observations of aurora at Cape Evans and Cape Denison would seem to have been very rare, and this perhaps is not surprising, as aurora was seldom seen in the south at Cape Denison.

§ 13.

Table IX makes a more detailed comparison of aurora and magnetic disturbance

TABLE IX.—*Incidence of Auroral and Magnetic Characters at Cape Denison.*

Auroral character ...	0·0			0·5			1·0			1·5			2·0		
Magnetic character ...	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
All auroral occurrences ...	293	157	31	120	65	13	252	267	59	56	98	37	1	8	26
Percentages	61	33	6	61	33	6	44	46	10	29	51	20	3	23	74
Zenithal aurora occurrences				8	5	2	39	59	10	10	29	8	0	2	8
Percentages				54	33	13	36	55	9	21	62	17	0	20	80

based on the auroral characters described in § 2. Table IX is constructed on similar lines to Tables IV and V. Take, for example, the hours of auroral character 1·0, which numbered in all 578. Of these 252, or 44 per cent., were hours of magnetic character 0 ; 267, or 46 per cent., were hours of magnetic character 1 ; and 59, or 10 per cent., were hours of magnetic character 2. Of the 578 hours there were 108 during which there was at least one observation of aurora in the zenith. Of these 108 hours, 39, or 36 per cent., had magnetic character 0 ; 59, or 55 per cent., had magnetic character 1 ; and, finally, 10, or 9 per cent., had magnetic character 2.

One of the most striking results in Table IX is that, if we may judge by the percentage figures, there is no certain difference, so far as magnetic disturbance is concerned, between hours when aurora was not seen and hours in which is was seen but was very faint.

As we pass up the auroral scale from 0·5 to 2·0 the percentage of hours of magnetic character 0 falls, and the percentage of hours of magnetic character 2 rises. Of the 35 hours awarded auroral character 2, only 1 had magnetic character 0, and 26 had magnetic character 2.

It may not be superfluous to state explicitly that the auroral characters were assigned at a much later date than the magnetic characters, and absolutely independently.

The hours of zenithal aurora in Table IX are the same as in Table VII, numbering in all 180. The distribution of magnetic characters in these 180 hours is not widely different from the distribution in the whole 1,002 hours of aurora included in the table. The percentage number of occurrences of character 0 is, however, slightly reduced in each auroral category. This difference would, of course, be somewhat amplified if we contrasted the hours of zenithal aurora with the 822 hours when aurora was seen only at lower altitudes. It should be noted, however, that on many of the 180 hours when aurora was seen in the zenith it was also seen at much lower altitudes, and it was sometimes brightest at the lower altitudes.

Unless the overhead position has some compensating disadvantages, the greater proximity to the station of an overhead aurora would naturally lead to its causing more magnetic disturbance than an aurora of equal intensity at a smaller altitude above the horizon. This consideration may well explain the slightly greater effectiveness of zenithal aurora suggested by Table IX. In view, however, of what has been said of the special tendency of zenithal aurora to occur in the hours near daybreak, the observed phenomenon may be partly due to the effects of twilight in leading to a slight underestimate of the auroral character.

§ 14.

Further evidence of the association of magnetic disturbance and bright aurora may be derived from some statistics as to the hourly magnetic ranges. There were only two months, June and September, 1912, for which measurements were made of the ranges of all hours of the day. In June there were 39 and in September 19 hours of bright aurora—i.e., with auroral characters 1·5 or 2·0. The mean ranges from the hours of bright aurora and from all hours, whether with or without aurora, were as follows :—

	Hours of bright aurora.		All days of the month.	
	H	*V*	*H*	*V*
June	54γ	77γ	26γ	33γ
September ...	42γ	46γ	17γ	22γ

In forming the all day means the influence of any diurnal variation was eliminated by omitting all hours of the 24 when aurora was not seen—i.e., all daylight hours—and weighting the others according to the number of times when aurora was actually seen. In both months the excess in the ranges for the hours of bright aurora is very large.

The measurement of magnetic ranges for the hours of bright aurora was not confined to June and September, 1912, but extended to all the hours of bright aurora included in Table IX for which the *D*, *H* and *V* records were all complete, and to a few additional hours of bright aurora in March, 1912. There were magnetic curves for part of that month, though they were not fully tabulated. The following were the mean values thus obtained for the hourly ranges :—

Year.	Number of hours.	D	H	V
1912 & 1913	227	37γ	38γ	43γ
1912	140	48γ	52γ	56γ
1913	87	20γ	17γ	21γ

As before, the changes in *D* are expressed in terms of the force equivalent. June and September may be taken as fairly representative of the months when aurora was seen in 1912. Thus we seem entitled to assume that in other months of that year, as well as in June and September, the magnetic ranges during hours of bright aurora were much above the average.

The comparatively small size of the hourly ranges on hours of bright aurora in 1913 may suggest that aurora exerted little if any effect on magnetic disturbance in that year. That, however, is probably not the true explanation. 1913, with a Wolfer's frequency of only 1·4, was a year of sunspot minimum, but 1912, with a sunspot frequency of 3·6, was nearly as quiet a year in Europe. In the Antarctic, however, whether we judge by the daily and hourly character figures, by the absolute daily ranges, or by the ranges of the regular diurnal inequalities, the magnetic changes regular and irregular were much smaller in 1913 than in 1912. For example, the ranges of the regular diurnal inequalities of *D*, *H* and *V* from all days of the winter season of 1913, using Greenwich days, were respectively only 53, 59 and 65 per cent. of the corresponding ranges for 1912. Thus a very large reduction was to be expected in the hourly ranges during hours of bright aurora in 1913, though hardly so large as that shown above.

There was a remarkable reduction in the amplitude of the magnetic changes at Cape Evans in 1912 as compared with 1911 ; and, as we now see, there was a very large reduction at Cape Denison in 1913—the year of sunspot minimum—as compared with 1912. It is obviously important to know whether this is accidental, or whether the 11-year period in magnetic phenomena has an exceptional development in the Antarctic (and Arctic). Comparative results from years near sunspot maximum would clearly possess much interest.

SUMMARY OF RESULTS.

§ 15.

Magnetographs were in operation at Cape Evans (77° 38′ S., 166° 24′ E.) during the greater part of 1911 and 1912, and at Cape Denison (67° 0′ S., 142° 40′ E.) from March, 1912, to August, 1913. The diurnal variations of magnetic disturbance at the two stations differ decidedly as regards the hour of maximum. Referred to

Greenwich or universal time, this is some 4 hours later at Cape Denison than at Cape Evans, a difference more than double the difference in local time. The time of occurrence of the principal maximum of disturbance at Cape Denison is roughly 2 hours G.M.T. the whole year round.

Active magnetic disturbance at Cape Denison is much less common in winter than in summer, and much less common by night than by day. Thus it is least common during the hours when aurora can be seen.

Very faint aurora seems to have no sensible effect on the occurrence of magnetic disturbance, but stronger aurora unquestionably has an effect, which increases with the intensity of the aurora.

Comparing the diurnal variation of aurora and magnetic disturbance at Cape Denison, it is found that the time of greatest frequency of bright aurora, 9.30 to 11 p.m. local time, synchronises at least approximately with the time of a secondary maximum of magnetic disturbance. During the next two or three hours there is a decline both in bright aurora and in magnetic disturbance, but in the early morning hours aurora begins to increase in frequency and to approach the zenith, and this seems to go on until aurora is interfered with by the approach of daylight. During this time magnetic disturbance is also increasing, and in its case the increase continues right up to the hour of maximum disturbance near local noon. This is at least consistent with the view that the overhead electrical storms which become visible at night as aurora continue in the day, and are, in fact, then most numerous. A fact also favourable to this view is that the diurnal variation in the frequency of active magnetic disturbance at Cape Denison exhibited the same general features in the midsummer months when no aurora was seen, as in the midwinter months when aurora was at its maximum.

At the same time, it must be allowed that near midwinter, 1912, there were a few comparatively short magnetic disturbances during the night, most, if not all, synchronous with specially brilliant aurora, which were much larger than any experienced at that season during the day. There was also an individuality about many of the minor night disturbances, most at least accompanied by aurora, which suggested the presence of some unique source of disturbance during a time varying from half an hour or less to two hours. This is, however, discounted, at least to some extent, by the fact that during the day, especially in summer, disturbance on a considerable scale was often so continuous that no short period disturbance could stand out, unless it were of altogether exceptional rapidity or amplitude. Also there were occasions during the day hours in summer when the rapid oscillations rivalled those occurring during the most brilliant winter aurora.

DISCUSSION.

Dr. G. C. Simpson said that all members of Scott's expedition would be grateful to Dr. Chree for his labours, without which the observations discussed would have been wasted. The observations on the aurora he would regard as qualitative rather than quantitative. The record taken hourly through the night had been very valuable in keeping the night watchman alert, but it was hardly to be expected that on leaving a warm hut the latter would spend time in a minute scrutiny of all parts of the sky ; although on one occasion the speaker had been called out to see a display of such beauty that he had spent no less than two hours in watching it, in scanty attire, in a temperature of −40 or −50 degrees Fahrenheit. Again, it was difficult to write down a significant record at times when the aurora was constantly changing and moving ; one might as well try to record observations on a firework display.

Capt. C. S. Wright said that he had looked forward to the Paper, because he had been anxious to see how the Cape Denison results fitted in with those from Cape Evans. He challenged the assumption that the early morning auroral maximum would have occurred later in the day but for the incidence of daylight, because at Cape Evans the corresponding maximum occurred earlier in local time, during darkness, and he felt sure that there the maximum was a real one. Then again the other maximum (corresponding to the midnight maximum of Cape Denison), which occurred at 7 p.m. in local time at Cape Evans, was quite different in character ; in the curve it consisted of a " pimple " in a general minimum, whereas the early morning maximum lay on the top of a crest. Further, the aurora itself had different characters at these two times, being irregular and rapidly shifting during the earlier maximum, but more uniform in the early morning. Did the author endorse the view that the maximum of magnetic disturbance may occur at " magnetic local midnight," when the sun is immediately below the magnetic meridian ?

The AUTHOR, in reply to the discussion, said that in favour of the view that the early morning auroral maximum should be placed later than the observed maximum was the fact that Sir Douglas Mawson's criterion showed an upward gradient right up to the incidence of daylight. As regards the effect of magnetic local time, he had suggested this as a factor some years ago, but a difficulty was that the magnetic axis is a mathematical fiction. The North and South magnetic poles are not antipodal, and though this fact might be of no account some 40,000 miles or more above the earth's surface, it was difficult to attach a definite meaning to magnetic time on the earth itself.

The CHAIRMAN, in thanking the author for his Paper, added that it had given great pleasure to Fellows present to welcome two members of Scott's expedition.

XXXII.—SERIES IN THE SPECTRUM OF TREBLY-IONISED TIN (Sn IV).

By K. R. Rao, *M.A.* (Madras University Research Scholar).

Abstract.

The Paper gives particulars of regularities observed in the spectrum of tin corresponding to the trebly-ionised stage of the element. Pairs of sharp and diffuse series are discovered which converge to a common limit with a sixteen-fold value of the Rydberg constant. The fundamental and super-fundamental series doublets are also indicated. Term values are evaluated from the related system of members by assuming a value for the term " *G*."

Great efforts have been made in the determination of the wavelengths of the lines of the tin spark spectrum. The plates were finally measured from spectra taken in the second order of a 5-ft. concave grating and an accuracy to about 0·05 Å.U. is claimed.

The experimental method of sorting out the lines due to this high stage of ionisation (Sn IV) is the same as that adopted previously by the writer in the case of Sn, Ga, In.

Introduction.

In accordance with the recent developments in the analysis of spectra it is to be expected that, while the neutral atom of tin will yield a spectrum derived from systems of terms of odd multiplicity, the spectra at successive stages of ionisation of the element will be constituted from terms of alternately even and odd multiplicity.

Although the number of lines in the tin arc spectrum is not large, the study of the spectrum from the series view point has not made great progress. Our knowledge is confined only to a table of frequency differences based on results obtained from absorption experiments,(1) the nature or the absolute value of the individual energy levels being yet undetermined.

Investigations for series relationships among the spark lines of tin are also meagre. No extended series in the spectra of the element in any of the ionised states have yet been detected, but in a recent paper(2) the present writer has set forth the leading members of the principal, diffuse (secondary) and fundamental series of a triplet system belonging to the spectrum of doubly-ionised tin (Sn III). Mention was also made of two pairs of the same frequency difference, and though no definite assignment* of the pairs was possible, they were found to form a Rydberg sequence with a $4R$ constant. This may be taken as evidence of the probable existence of doublets representing Sn II. It is the purpose of this Paper to present regularities in the spectrum of tin corresponding to the third-step ionisation of the atom, the system of series being characterised by a sixteen-fold value of the Rydberg constant.

Experimental.

As is usual in investigations of this nature, the spark spectrum of tin has been examined under different degrees of excitation. The sources included the spark between pure electrodes of tin in air, in vacuum and in an atmosphere of hydrogen at varying pressures, and also the arc in vacuum. The ordinary spark in air and the vacuum arc served well to eliminate the lines due to the lower stages of ionisation of the element. As in previous experiments, recourse was also had to the method of studying the spectrum when the inductance and capacity in the circuit were varied. In general, the lines of Sn IV are found to be best developed in the condensed spark in hydrogen at low pressures, while they are feeble and diffuse, or perhaps absent, in the condensed spark in air or in hydrogen at atmospheric pressure.

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* The magnitude of the separation (625) suggests that it may be the " second p " separation, while the limit and terms suggest the assignment $x-\varphi$ of the type found in Si II.

For preliminary observation of the spectra an ordinary constant deviation spectrograph and a plane grating spectrograph were used for the visible region, while a quartz spectograph was utilised for the ultra-violet. But the wavelengths of the lines were finally determined from spectrograms taken in the second order of a 5-ft. concave grating, recently purchased and mounted by Prof. Narayan, giving a dispersion of about 5·67 Å.U. per mm. In the region below about $\lambda 2,600$ these values were also checked by measurements from plates taken with a Hilger quartz instrument giving a dispersion of about 7 Å.U. per mm. at $\lambda 2,450$, the wavelength being calculated by the use of the simple Hartmann formula. The plates were measured with a comparator of the Cambridge Scientific Instrument Co., reading to 0·01 mm. Each plate was measured a large number of times by two different observers, and the average of the readings was taken. The arc lines of tin, for which the accurate measures of Arnold(3) have been adopted, served as standard lines, and for the region between $\lambda 2,200$-2,000 the usual standards of copper(4) and aluminium spark lines were also utilised. In general, the wavelengths may be claimed to be accurate to about 0·05 Å.U. Great labour was bestowed in measuring up the plates, as the existing measures of many of these lines were far from being suitable for the present purpose. A detailed list of the spark lines of tin, giving the stage to which each line is believed to belong, will be presented in a separate communication.

The notation is the same as that used in the previous Papers. The subscript denotes the inner quantum number. The first term is denoted by " 1 *P*," the second by " 2 *P*," and so on in each case, and when only one term is found the numeral is omitted.

IDENTIFICATION OF THE SERIES.

The method of identification of the series in Sn IV was, in the first instance, by applying to the case of the spectra of silver-like atoms the relativity laws, the fecundity of the application of which to a long chain of atoms of the same electronic structure has been clearly brought out in a series of Papers by Bowen and Millikan. The chief members of the secondary series of the spectrum of In III, resembling those of Ag I, Cd II, have already been indicated in an earlier communication.(5) The location of these in the spectrum of Sn IV was therefore greatly facilitated. The regular and irregular doublet-law-progressions with atomic number, as shown below, indicate the value of the frequency of $2S_1 - 2P_2$ to be approximately 26,000 cm.$^{-1}$, and the doublet separation $(2P_1 - 2P_2)$ to be about 2,200.

Element.	$2S_1 - 2P_2$ ν	Diff.	$2S_1 - 2P_2$ ν	Diff.
Ag I	(5,946)		(5,741)	
		6,447		5,978
Cd II	12,393		11,719	
		6,655		5,992
In III	19,048		17,711	
		6,843		6,003
Sn IV	[25,891]		23,714	

(Fourth power law) $(Z-s)=\sqrt[4]{\Delta\nu/0{\cdot}0135}$.

Atomic Number (Z).	Element.	$\Delta\nu$ ($2P_1-2P_2$)	$Z-s$	s (screening) constant).	Δs
47	Ag I	202·9	11·08	35·82	2·76
48	Cd II	672·82	14·94	33·06	1·80
49	In III	1,337·4	17·74	31·26	1·30
50	Sn IV	[2,177·4]	[20·04]	[29·96]	

Comparison of the separations with the squares of net nuclear charges of the four atoms Ag I to Sn IV gave about 2,190 cm^{-1} for the second " P " separation. Examination of the spectrum showed at once the strongly enhanced doublet λλ3,861·26, 4,215·74 to fit in perfectly into the above progressions. The component on the short wavelength side is certainly stronger than the other, showing that the doublet is of a principal series. It will be of interest to observe, also, the variation of the doublet separation with the square of the atomic number of the elements C, Si, Sn of the same vertical group of the periodic table.

Atomic Number Z.	Element.	$\Delta\nu$ $1P_1-1P_2$	$\Delta\nu/Z^2$	$\Delta\nu$ $2P_1-2P_2$	$\Delta\nu/Z^2$
6	C IV	107·4	2·984		
14	Si IV	460·0	2·347	162	0·8264
50	Sn IV	6507·0	2·603	2177	0·8712

The progression of the member of the diffuse series indicated that the strong line λ2,848·51, which certainly belongs to Sn IV, may be $2P_2-2D_3$.

Variation of $2P_2-2D_3$.

Element.	ν	Diff.
Ag I	(5,715)	9,149
Cd II	14,864	9,924
In III	24,788	10,308
Sn IV	[35,096]	

But for a long time the examination of the quartz spectrograms failed to reveal its companion $2P_1-2D_2$, which, according to the intensity rule, must also be equally strong. However, the second order spectrum (Fig. 3-B), taken with the concave grating, distinctly showed the strong lines λ2,706·23, which, in behaviour, is identical with λ2,848·51. Its proximity to the intense arc line λ2,706·5 caused the initial difficulty. The pair and satellite given below were therefore taken as the required diffuse member.

λ I.A. (Int.).	υ (vac.).	Δυ
2,875·73 (5)	34,763·6	332·2
2,848·51 (10)	35,095·8	2,177·21
2,706·23 (9)	36,940·8	

The detection of this member removed all doubt as to the certainty of the identification.

A further search among the enhanced lines belonging to Sn IV for pairs with the above separation 2,177·4 resulted in the finding of the two following :—

λ I.A.	Int.	υ	Δυ
3,071·51	(8)	32,547·9	2,177·6
2,887·79	(10)	34,618·4	107·1
2,878·89	(4)	34,725·5	
2,659·85	(4)	37,585·0	2,178·0
2,514·14	(4)	39·763·0	

The first of these is accompanied by a satellite, and the disposition of the group shows that it must be an inverted diffuse member, while the second is taken to be a pair of the sharp series.

The consistency of the allocation of these lines is shown by calculating the formulæ for the two series. The brighter components of the pairs are used for the determination of the limits.

(1) Limit from the sharp series—

$$s_1(2)=2P_2-2S_1=-25{,}891{\cdot}4$$

$$s_1(3)=2P_2-3S_1=\ 37{,}585{\cdot}0$$

$$s_1(m)=130{,}191-\frac{16R}{[m+1{\cdot}35313]^2}$$

i.e., limit $2P_2=130{,}191$.

(2) Limit from the diffuse series—

$$d_3(2)=2P_2-1D_3=-34{,}618{\cdot}4$$

$$d_3(3)=2P_2-2D_3=\ 35{,}095{\cdot}8$$

$$d_3(m)=132{,}841-\frac{16R}{[m+1{\cdot}23722]^2}$$

limit $2P_2=132{,}841$.

The agreement between the limits is as close as can be expected from the use of the simple Rydberg formula.

The Primary Series.—The chief lines of the Sn IV spectrum constituting the primary series are to be expected in the extreme ultra-violet. But the observations of the spark spectrum of tin in the vacuum grating region are not satisfactory for a sure identification of these series of lines. From the formula calculated above from the sharp series there results for the first principal series doublet

$$2P_2=130{,}191=\frac{16R}{[3\cdot 67136]^2}$$

$$2P_1=132{,}369=\frac{16R}{[3\cdot 64111]^2}$$

——	υ	Δυ
$1S_1-1P_2=$	71,030·4	5,684·8
$1S_1-1P_1=$	65,345·6	

Carroll(6) has already located from a consideration of the sequence of atoms Ag I to Sn IV the pair

——	υ	Δυ
$1S_1-1P_2=$	76,063	6,507
$1S_1-1P_1=$	69,556	

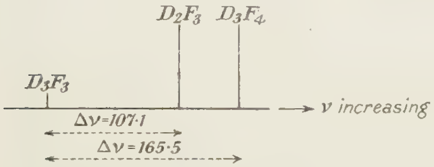
The agreement between the observed and calculated positions is not quite perfect, and this must probably be due to the approximate character of the formula employed. The position of the first diffuse series member can also be approximately determined through the observed inverted doublet, but the data of Lang(7) do not show the required pair and satellite with the appropriate separation. The vacuum grating measurements must be more exhaustively made before this member can be fixed correctly in the light of these results.

Fundamental Series.—The location of the members of the fundamental series is next considered. In the case of most spectra the first member of this series is very prominent, and characterised by a high intensity and diffuse nature of the lines. It is expected that the corresponding member in the spectrum of Sn IV must also have been strongly excited under the conditions studied. And the separation $\triangle\nu D_{3\ 2}$ is known from the disposition of the inverted doublet $1D-2P$ to be equal to 107·1 cm.$^{-1}$ From the approximate value of the first " D " and " F " terms, as judged by the sequence of terms of Ag I, etc., and also from the general run of these corresponding members in this sequence,

——	υ
Ag I	5439
Cd II	18588
In III	33228
Sn IV	

it is seen that this member very probably occurs between $\lambda 2{,}100 \rightarrow \lambda 2{,}000$.

Exposures of about an hour and a half with the large size Hilger quartz spectograph on Schumann plates brought out clearly the spectrum to the very limit of the instrument. The first order of the sharply focussed concave grating was also made use of for a careful examination of the spectrum in this region. The line λ2,040 is seen faintly on the concave grating plate, while the quartz spectrum extended up to λ2,072. The measurements of Lang begin from λ2,040 and extend towards the region of shorter wavelengths, so that it is believed that a knowledge of the spectrum in the entire region that is required for the identification of this member is available. As a result of examination of the spectrum down even from λ2,400, it is found that there is no prominent pair with the appropriate separation 107·1. This at first caused great anxiety, but it was afterwards discovered, as will be presently seen, that the difficulty is due to the larger energy difference between the first doublet "*F*" levels than that between the first doublet "*D*" levels. The strong pair of lines shown in the following table was prominently observed from the outset. That this pair belongs to the trebly-ionised stage is unquestionable, and it has been classified as due to Sn IV by Kimura and Nakamura.(8) The magnitude of the separation 165·5 shows that it cannot possibly be either a "*P*" or a "*D*" separation. The region λ2,220 is exactly where the first pair of the super-fundamental (*FG*) series may be expected. The corresponding members in the spectra of In III and Ga III have been found to be fairly intense, as indicated in a previous Paper. It is therefore supposed that the above pair constitutes the combination $(F_{43}-G)$ doublet.



λ I.A.	Int.	υ	Δυ
2,229·18	(8)	44,845·6	165·5
2,220·98	(8)	4,501·1	

If so, the first member of the fundamental series must consist of two strong lines with a separation (165·5 − 107·1) equal to 58·4, accompanied by a faint satellite, the structure being as indicated in the above diagram.

A search for this pair at once showed the following doublet, which agrees well with the above view. But the satellite could not be traced, perhaps owing to its faintness and the region in which it must appear. As for the second fundamental series, there is a pair $\lambda\lambda$3,779·6, 3,732·90 with the separation $\triangle\nu=331{\cdot}1$, or perhaps the pair and satellite 3,779·63, 3,764·49, 3,732·90, which may be assigned to be the first member. But the second (*FG*) combination line or pair has not been found, and much reliance cannot be placed on this combination, as the second "*F*" term value calculated from this is much too small.

λ I.A.	Int.	υ (vac.)	Δυ
2,084·27	(8)	47,963·0	58·1
2,081·75	(8)	48,021·1	

The consideration of the location of other combination pairs—e.g., of the third series—from among the fainter lines of the enhanced spectrum is deferred for the present till the spectrum of Sn III has been examined in greater detail. This and the study of the series representing Sn II are still in progress.

The Diffuse Term Separations.—A peculiarity noticed in the " P " separations exhibited in this spectrum deserves mention. Carroll⁽⁹⁾ has called attention to a rule that $\triangle\nu/c^2$ is constant for a given sequence. The following table gives the first and second " D " term separations in silver-like atoms and the values of $\triangle\nu/c^2$.

	$(1D_2-1D_3)$	$\Delta\nu/c^2$	$2D_2-2D_3$	$\Delta\nu/c^2$
Ag I	20·3	20·3	10·6	10·6
Cd II	154	38·5	73·5	18·4
In III	283	31·4	181·4	20·2
Sn IV	107	6·7	332·2	20·8

It is seen that the second " D " term separation agrees with the rule, but the first separation falls much below the value suggested by the rule, and, in fact, very peculiarly below even the second " D " separation. It is significant here to point out that the " D " separations are recorded in Al III but not in Sn IV.

Term Values.—The series presented form a connected system of members and the term values are evaluated, as usual, through the frequencies of the individual lines, by assuming the value of the " G " term to be equal to 70,400 cm.$^{-1}$($\nu/c^2=$ 4,400). Owing to the lack of the first diffuse doublet, the correct evaluation of the largest term $1S_1$ of the spectrum, and therefore of the exact value of the fourth ionisation potential of tin, is not yet possible. Table I gives the values of the terms calculated, with the effective quantum number against each, obtained from the usual formula

$$\nu=\frac{16R}{(n-q)^2}$$

where n is the total quantum number and $(n-q)$ the effective quantum number.

TABLE I.

Term Designation.	Term Value.*	Effective Quantum number.
G	[70,400]	
F_4	115,246	3·9032
F_3	115,411	3·9004
$1D_3$	163,267	3·2793
$1D_2$	163,374	3·2783
$2D_3$	93,553	4·3322
$2D_2$	93,885	4·3245
$2P_2$	128,648	3·6943
$2P_1$	130,826	3·6634
$2S_1$	154,540	3·3707
$3S_1$	91,063	4·4419

* The terms are given correct to the nearest unit.

The term $2P_2 = 128,648$, determined thus, agrees well with the value 130,191 obtained as a limit from the sharp series.

Comparison of Terms.—In Table II a comparison is made of the series terms of the four atoms of similar electron structure. The terms, as usual, are divided by 1^2, 2^2, 3^2, 4^2.

Table II.

	$2S_1$	$3S_1$	$2P_2$	$1D_3$	$2D_3$	F_4
Ag I	18,540	9,209	12,596	12,331	6,881	6,892
Cd II	13,347	[7,300]	10,248	11,633	6,532	6,986
In III	11,228	6,500	9,111	10,821	6,357	7,128
Sn IV	9,659	5,692	8,041	10,204	5,847	7,203

Finally, for the sake of convenience, the series lines indicated here are collected in Table III.

Table III.

Classification.	λ I.A.	Int.	ν (vac.).	Δν.
$2S_1 - 2P_2$	3,861·26	(10)	25,891·4	2,177·4
$2S_1 - 2P_1$	4,215·74	(7)	23,714·0	
$2P_2 - 3S_1$	2,659·85	(4)	37,585·0	2,178 1
$2P_1 - 3S_1$	2,514·14	(4)	39,763·0	
$1D_2 - 2P_1$	3,071·51	(8)	32,547·9	2,177·6
$1D_3 - 2P_2$	2,887·79	(10)	34,618·4	107·1
$1D_2 - 2P_2$	2,878·89	(5)	34,725·5	
$2P_2 - 2D_2$	2,875·73	(5)	34,763·6	332·2
$2P_2 - 2D_3$	2,848·51	(10)	35,095·8	2,177·2
$2P_1 - 2D_2$	2,706·23	(9)	36,940·8	
$1D_3 - F_3$	...		[47,855·9]	107·1
$1D_2 - F_3$	2,084·27	(8)	47,963·0	165·2
$1D_3 - F_4$	2,081·75	(8)	48,021·1	
$F_4 - G$	2,229·18	(9)	44,845·6	165·5
$F_3 - G$	2,220·98	(9)	45,011·1	

In conclusion, I gladly take this opportunity of acknowledging my great indebtedness to Prof. A. L. Narayan, M.A., D.Sc., F.Inst.P., who has suggested this investigation, and given me valuable guidance throughout its course.

EXPLANATION OF PLATE.

Figs. 1, 2, 3 are portions of spectra taken of the condensed spark in hydrogen at low pressures between electrodes of pure tin.

Fig. 1.—Quartz spectrum. (*a*), (*b*), (*c*) are taken with increasing inductance.

Fig. 2.—Quartz spectrum in the ultra-violet below $\lambda 2400$, taken on a Schumann plate.

Fig. 3 (A).—First order concave grating spectrum.

Fig. 3 (B).—Second order concave grating spectrum, showing the line $\lambda 2706 \cdot 23$ distinctly resolved from the arc line $\lambda 2706 \cdot 5$.

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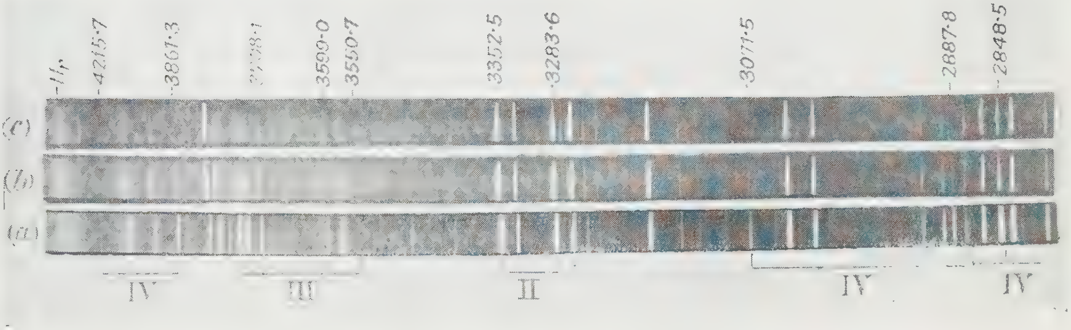


Fig. 1.—Quartz Spectrogram.

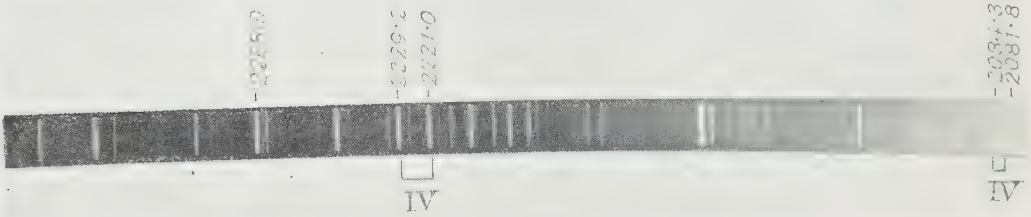
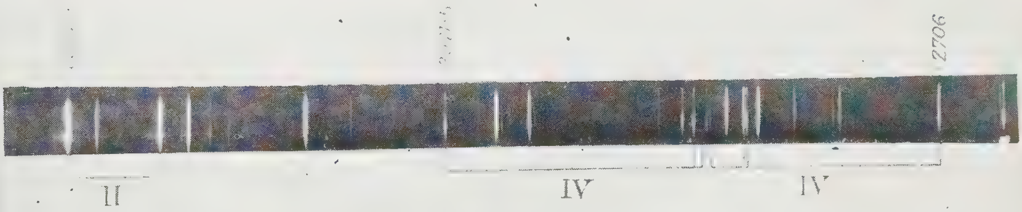
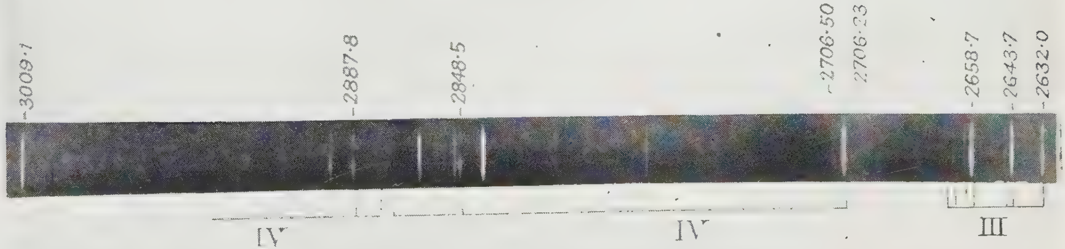


Fig. 2.—Quartz Spectrogram.



A (First Order)



B (Second Order)

Fig. 3.—Concave Grating Spectrograms.

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XXXIII.—THE LATENT HEAT OF EVAPORATION OF SULPHUR.

By J. H. Awbery, *B.A.*, *B.Sc.*, Physics Department, The National Physical Laboratory.

Received March 31, 1927.

Abstract.

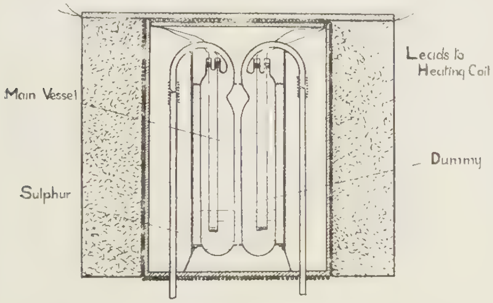
The latent heat of evaporation of sulphur was determined by finding the loss of weight of a vessel full of sulphur when energy was dissipated in it at a known rate. Heat losses were prevented by immersing the vessel in the vapour of sulphur; a method of correction for the heat loss by having a dummy vessel with a smaller heating coil, and using the differences in energy and in weight evaporated, for the two vessels, was tried but gave unsatisfactory results.

The value found for the latent heat was 79, the accuracy being estimated at 2 per cent.

The principle of the method to be described is that of measuring the quantity of sulphur boiled off from a vessel, when a known amount of heat energy is supplied. If the loss of heat from the vessel can either be eliminated or estimated, the latent heat is given directly from the two quantities.

Preliminary Series.

In some preliminary experiments efforts were made to eliminate the heat loss by using two similar vessels containing sulphur, and placing them symmetrically in an electric resistance furnace. A radiation shield was interposed between the vessels and the walls, as shown in Fig. 1, and the temperature in the sulphur was maintained as near to the boiling point as was possible, by adjustment of the furnace current. Thus the heat loss should be the same for each, and would be eliminated by taking differences.



Apparatus for Preliminary Experiments.

Fig. 1.

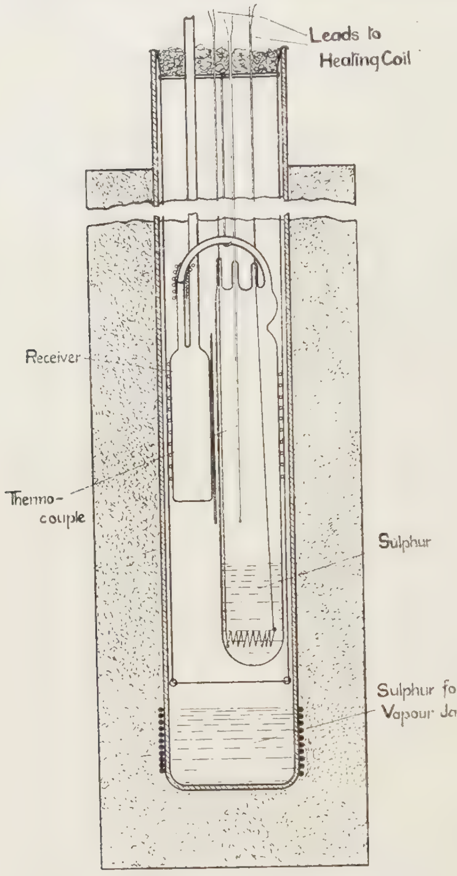
Each of the vessels, as may be seen in the figure, had an outlet bent over to face downwards. To this was attached a straight tube of Pyrex glass, projecting through the base of the furnace. The vessels were provided with heating coils of different lengths, the two being connected in series and each provided with potential leads; thermocouples were also inserted into the vessels through narrow tubes, similar to those through which the leads for the heating current passed. All these fine tubes were packed with asbestos wool.

Two cases then arise. If the furnace temperature is initially slightly above the boiling point of sulphur, both vessels will slowly distil off sulphur, and when the current in the heating coils is switched on they will both continue to receive energy from the furnace walls at the same rate as before (since both are at the boiling point). The energy dissipated in the heating coils will be employed entirely in vapourising sulphur, so that the difference in the amounts volatilized should correspond to the difference in the energies dissipated in the respective coils.

The other case occurs if the furnace is initially a little below the boiling point. In this case the energy supplied has first to raise the tubes and their contents to this temperature, after which boiling commences, but a part of the energy is radiated all the time to the furnace walls. It is clear that, whatever the initial temperature, the method demands that the tubes should be similar and symmetrically placed, so that the one with the smaller heating coil either gains or loses heat to the same extent as the other. If this condition is fulfilled, the difference in energy should again correspond to the difference in weights evaporated.

The energy was measured by readings of current and potential drop, and the weight of sulphur determined by weighing the container before and after.

The results of a number of experiments, in which the conditions were widely varied, indicate the difficulty of attaining the conditions in which the heat losses are sufficiently equal to be eliminated in the differences. They gave, as the latent heat at the normal boiling point, the following figures (in calories per gram): 80·3, 70·5, 90·0, 63·7, 69·1, 66·0, 70·0; mean, 72·8.



Final Apparatus

FIG. 2.

SECOND SERIES.

The method was therefore considerably modified, and a new series of experiments undertaken in the apparatus of Fig. 2.

The furnace was replaced by a sulphur bath, which automatically provided for the maintenance of the correct temperature, eliminating even the difficulty of the variation with barometric pressure. Experiments with a thermocouple in the experimental vessel showed that the temperature of the boiling point was reached to within the accuracy of the couple, whilst prolonged experiments with the tubes in the sulphur bath, but with no current in the heating coil, showed no loss of weight due to evaporation. Hence the pair of vessels were no longer necessary, since there was no gain or loss of heat other than that due to the heating current. The series of experiments was therefore carried out with only one vessel, surrounded by a radiation shield and inserted in the sulphur vapour, as in Fig. 2.

Since the outlet would now be immersed in the vapour of sulphur, precautions had to be taken to prevent its ingress after the heating current in the coil was switched off. The means of avoiding this is indicated in Fig. 2. A bulb with two vertical outlet tubes was attached to the main vessel, one tube projecting out of the bath to serve as an air condenser. Thus the sulphur evaporated during an experiment was collected in this bulb, and a check on its weight was obtained by weighing both the main vessel and the collector before and after an experiment. The joint between the two was made by winding asbestos paper tightly over the two tubes, whilst fitted end to end, and binding it with asbestos string. It was found that this makes an excellent joint, if the asbestos paper is moistened immediately before use. A summary of the experiments is given below :—

Observation period. (Minutes.)	Heating current. (Amps.)	Latent heat at the boiling point (444·5°C.) (Cals. per gram.)
6	2·1	78·5
7	2·2	82·0
4	2·0	77·5
8	2·1	81·4
7	1·4	76·0
8	1·1	78·8
		——Mean 79·0

Taking into account the possible systematic errors, the accuracy of this result is likely to be of the order of 2 per cent.

COMPARISON WITH PREVIOUS RESULTS.

Only two determinations appear to have been made previously. One is due to Person, who worked under reduced pressure, and stated that the temperature at which he worked was 316°C. The result, obtained calorimetrically, was 362 calories per gram. Another estimate was made in 1914 by Beckmann and Liesche, from the rise of boiling point of solvents when sulphur was added, as 64·8, but this involves a knowledge of the molecular weight. These authors accept estimates from chemical data of the relative quantities of S_6 and of S_8 respectively, but appear to assume that the proportions of the two kinds of molecules is the same in the vapour and liquid phases.

ACKNOWLEDGMENTS.

I have to thank Dr. G. W. C. Kaye, Superintendent of the Physics Department, for the ready facilities he has given for carrying out this work. I am also indebted to Mr. A. R. Challoner for his assistance in taking many of the observations, and for constructing the apparatus.

DISCUSSION.

Capt. C. W. HUME : The author suggests the possible occurrence of small systematic errors. It is noticeable that the value of the specific heat rises quite definitely with the quantity of sulphur evaporated, if this be taken as proportional to the product of the " observation period " and the square of the current ; though there is a marked exception in the case where the current, or rate of evaporation, is exceptionally small. Perhaps these considerations may suggest some source of systematic error, and enable the most reliable value of the latent heat to be selected.

Dr. E. H. Rayner pointed out that a certain quantity of heat would be expended in filling the vessel with vapour which would not pass out.

Dr. Ezer Griffiths, in reply to the discussion, said that the chief systematic error would arise from the carrying over of liquid particles by the vapour. The kink in the walls of the vessel, just under the outlet, was intended to prevent this, but a large number of experiments would have to be made for a conclusive trial of its efficiency. It was presumed that the vessel was initially full of sulphur vapour, as it had been immersed in boiling sulphur for some time before the experiment began.

XXXIV.—THE REFRACTION AND DISPERSION OF GASEOUS CARBON TETRACHLORIDE.

By H. LOWERY, *M.Sc.*, *F.Inst.P.*, Head of the Physics Department, Technical College, Huddersfield.

Received April 27, 1927.

ABSTRACT.

The refractive index of gaseous carbon tetrachloride has been found for the green mercury line (λ5461), the result being expressed in connection with the density of the gas, that is, so as to show the refractivity of the gas by the same number of molecules as 1 c.c. of hydrogen contains at N.T.P.

Adopting the value 1·001799 for the refractive index under these conditions, the dispersion of the gas has been studied over the range λ4800 to λ6700, and is represented by the expression

$$\mu - 1 = \frac{13{\cdot}543 \times 10^{27}}{7831{\cdot}7 \times 10^{27} - \nu^2}$$

ν being the frequency of the light.

I. INTRODUCTION.

IN continuation of an investigation on the refraction and dispersion of gaseous compounds, the refraction and dispersion of gaseous carbon tetrachloride have been studied.

Mascart* found the refractivity of gaseous carbon tetrachloride, relative to that of air, to be 6·05 for sodium light. No measurements of the dispersion appear to have been made.

II. EXPERIMENTAL.

The optical arrangements were the same as those in the work on gaseous carbon disulphide,† a Jamin interferometer being employed in connection with a Hilger constant deviation spectroscope as monochromatic illuminator.

To determine the refractive index of the gas, preliminary experiments were carried out, using a method employed by C. and M. Cuthbertson,‡ in which the substance under investigation is introduced (in the liquid state) into the refraction tube by means of a small capillary tube. Full details of the method are given in the Paper referred to.

In the case of gaseous carbon tetrachloride, however, it was found more convenient to work with apparatus similar to that employed in the experiments on carbon disulphide. The vapour pressure of carbon tetrachloride at 30°C. is 14 cms., and this pressure is sufficient to allow of the order of 250 interference fringes being counted under the conditions of the experiments.

A reservoir of pure liquid carbon tetrachloride was put into communication with the refraction tube by a connecting tube lagged with asbestos fibre, and surrounded with a coil of wire which could be heated by an electric current. Both refraction tubes were mounted between the interferometer plates in a tank and were kept throughout an experiment at a steady temperature of about 45°C. by warm water. The interferometer plates were screened from the heat of the tank of water by sheets of asbestos.

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* Comptes Rendus, LXXXVI, p. 1182 (1878).

† Proc. Phys. Soc., Vol. 38, p. 470 (1926).

‡ Phil. Trans., A, Vol. 213, p. 15 (1913).

Before an experiment was begun, the carbon tetrachloride was solidified in the reservoir by means of solid carbon dioxide, and the refraction tubes thoroughly exhausted. It was then gradually warmed up to about 30°C., the number of interference bands displaced in the telescope being counted as the gas entered the refraction tube. Since the density bulb, refraction tube and connecting tube (surrounded by the heating coil) were at a temperature considerably higher than that of the reservoir, no condensation could occur in them. The amount of vapour which passed into the refraction tube was determined by means of the density bulb, and the refractive index was calculated from the expression

$$\mu-1=\frac{n\lambda}{l}\left(\frac{\text{standard density}}{\text{density observed in the experiment}}\right)$$

where n is the number of interference bands counted, l the length of the refraction tubes, and λ the wavelength of the light employed.

Pure liquid carbon tetrachloride was supplied by Messrs. British Drug Houses, Ltd.

III. Results.

(*a*) *Refractive Index of Gaseous Carbon Tetrachloride.*

Ten experiments were performed in order to determine the refractive index of gaseous carbon tetrachloride for the green mercury line (λ5461), with the following results:—

$(\mu-1)\times10^6$—1795, 1798, 1805, 1802, 1794,
1799, 1804, 1798, 1795, 1800.
Mean—1799 (λ5461).

These values were worked out from the expression above, so that they show the refractivity of gaseous carbon tetrachloride by the same number of molecules as 1 c.c. of hydrogen contains at N.T.P.

From the data C=12·000, H=1·008, Cl=35·457, and density of hydrogen=0·08985 grams per litre at N.T.P., the standard density of carbon tetrachloride vapour is 6·856 grams per litre.

In the present work the *mean* density of carbon tetrachloride vapour is found to be 6·814 grams per litre, the reduction being effected by the expression

$$d=d_0\cdot\frac{(t+273)}{273}\cdot\frac{760}{p}$$

where d is the reduced density, d_0 the observed density at pressure p mms. of mercury and temperature t° C. The experimental density of carbon tetrachloride vapour is given in Watt's Dictionary of Chemistry as lying between 5·24 and 5·33 (air=1), that is, between 6·76 and 6·89 grams per litre.

(*b*) *Dispersion of Gaseous Carbon Tetrachloride.*

The dispersion was measured in six experiments, with the results shown in the accompanying table.

The second column contains the results actually obtained in the experiments. From these the constants in the Sellmeier dispersion formula (single term) have been obtained by the method of least squares, the resulting expression being

$$\mu - 1 = 13{\cdot}543 \times 10^{27}/(7831{\cdot}7 \times 10^{27} - \nu^2).$$

The values in the third column have been calculated from this expression.

Dispersion of Gaseous Carbon Tetrachloride.

λ in Å.U.	$(\mu - 1) \times 10^6$.		Difference.
	Observed.	Calculated.	
Li 6708	1774, 0	1774, 6	+6
Cd 6438	1778, 4	1778, 6	+2
Li 6104	1784, 6	1784, 3	−3
Hg 5770	1791, 8	1791, 1	−7
Hg 5461	1799, 0	1798, 6	−4
Cd 5086	1810, 1	1809, 6	−5
Cd 4800	1819, 6	1820, 0	+4

(*c*) *Comparison between Mascart's Work and the Present.*

For λ5893, the above expression gives $\mu = 1{\cdot}0017884$ as the refractive index expressed in terms of the density of the gas. To reduce this value to the corresponding value under N.T.P. conditions, it must be altered in the ratio

$$\text{(Experimental density at N.T.P.)}/\text{(Standard density)} = 6{\cdot}814/6{\cdot}856.$$

The reduced value so obtained is 1·001777 (for λ5893 and N.T.P. conditions). Mascart's value is 1·001768 if the refractive index of air be taken as 1·0002923 under the same conditions.

The author's thanks are due to Professor W. L. Bragg, F.R.S., and Mr. C. Cuthbertson, F.R.S., for the loan of apparatus and much helpful advice.

XXXV.—REGULARITIES IN THE SPECTRUM OF IONISED NEON.

By P. K. Kichlu, *M.Sc.*, Research Scholar, University of Allahabad.

Received May 17, 1927.

Abstract.

A number of lines lying between λ7282 and λ3142 occurs in the condensed discharge spectrum of the more volatile gases of the air. These have been attributed to singly ionised neon, and the present Paper comprises an analysis which confirms this view.

LIVEING* and Dewar in 1900 observed a large number of lines between λ7282 to λ3142 by passing a condensed electric discharge through tubes filled with the more volatile gases of air. They were unable to trace the source from which they were derived. Fourteen years later Merton† obtained most of these lines in tubes filled with pure neon. None of these, however, were included in Paschen's‡ analysis of the arc spectrum of neon. More recently L. and E. Bloch§ and Dejardin have obtained these lines by the method of electron-bombardment, and found that they come out strongly at 49 volts. On this basis, they ascribe these lines to singly ionised neon. The present analysis confirms the indentification of L. and E. Bloch and Dejardin beyond doubt and is in strict accord with Hund's theory of complicated spectra.

We may begin by writing down the terms which may be expected according to Hund's theory :—

Structure Diagram of Ne.$^+$

$$\begin{tikzcd}
K & & & & \\
2 & L_1 & L_2 & & \\
 & 2 & 5 & & \\
 & & M_1 \arrow[r] & M_2 \arrow[r] \arrow[d] & M_3 \arrow[d] \\
 & & & N_1 \arrow[r] & N_2
\end{tikzcd}$$

Table of Theoretical Terms.

Position of valence electrons.		Terms calculated.	Terms observed.
(*a*)	$5L_2$	${}^2P$	
↓			
(*b*)	$4L_2M_1$	${}^4\overline{P}$ ${}^2D$ ${}^2S$ ${}^2P$	${}^4\overline{P}$
↓			
(*c*)	$4L_2M_2$	${}^4\overline{D}$ ${}^4P$ ${}^4\overline{S}$ ${}^2\overline{D}$ ${}^2P$ ${}^2\overline{S}$	${}^4\overline{D}$ ${}^4P$ ${}^4\overline{S}$
↓			
(*d*)	$4L_2M_3$	${}^4\overline{F}$ ${}^4D$ ${}^4\overline{P}$ ${}^2\overline{F}$ ${}^2D$ ${}^2\overline{P}$	${}^4\overline{F}$ ${}^4D$ ${}^4\overline{P}$
(*e*)	$4L_2N_1$	${}^4\overline{P}$ ${}^2D$ ${}^2S$ ${}^2\overline{P}$	

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* Liveing and Dewar. Proc. Roy. Soc., A, Vol. 67, p. 467 (1900).

† T. R. Merton. Proc. Roy. Soc., A, Vol. 89, p. 447 (1914).

‡ F. Paschen. Ann. d. Phys., Vol. 60, p. 405 (1919).

§ L. and E. Bloch and Dejardin. Jour. de Phys., Vol. 7.

We shall prefix successively the small letters *a*, *b*, *c*. . . . to the various levels arising from different electronic configurations to distinguish those of the same type, e.g., all terms due to

$4L_2M_1$ will have the prefix " b,"
$4L_2M_2$ will have the prefix " c," etc.

The clue to the classification of the lines of ionised neon was furnished by the $c^4P-d^4\bar{P}$ multiplet forming a distinct and isolated group of lines between $\lambda\lambda$ 2799 and 2756. The deepest terms so far found correspond to $b^4\bar{P}$ obtained from the combination $4L_2M_1$. These account for some of the strongest lines present in the spectrum, and occurring as reversals in L. and E. Bloch and Dejardin's list. Obviously the lines arising from a^2P, if they are present at all, would be situated in the far ultraviolet and lie outside the region investigated.

The Multiplets.

	$b\ {}^4\bar{P}_1$	298·8	$b\ {}^4\bar{P}_2$	518·0	$b\ {}^4\bar{P}_3$
$c\ {}^4P_1$ 182·5	26650·2 (4)		26949·0 (7*R*)		
$c\ {}^4P_2$ 222·7	26467·6 (8*R*)		26766·6 (7)		27284·5 (9*R*)
$c\ {}^4P_3$			26543·4 (8*R*)		27061·8 (10*R*)
$c\ {}^4\bar{D}_1$ 144·2	29891·8 (5)		30190·8 (4)		
$c\ {}^4\bar{D}_2$ 249·7	29747·8 (5)		30046·5 (5)		30564·9 (2)
$c\ {}^4\bar{D}_3$ 337·3			29796·9 (7)		30315·1 (8)
$c\ {}^4\bar{D}_4$					29977·4 (10*R*)
$c\ {}^4\bar{S}_2$	33005·7 (4)		33304·5 (7)		33822·7 (7)

The lines

(1) 3713·07
26924·2 (10*R*)

(2) 3694·19
27061·8 (10*R*)

(3) 3664·05
27284·5 (9*R*)

have been listed by Paschen as arc lines. They are without doubt spark lines, and represent some of the fundamental lines of the ionized element. Their intensity is considerably enhanced in the condensed discharge.

The multiplets obtained between the terms of the combinations $4L_2M_2$ and $4L_2M_3$ are shown below :—

	$c\,{}^4P_1$	182·5	$c\,{}^4P_2$	222·7	$c\,{}^4P_3$	$c\,{}^4\bar{S}_2$
$d\,{}^4\bar{P}_1$ 304·8	36082·3 (1)		36264·8 (3)			29727·7 (1)
$d\,{}^4\bar{P}_2$ 377·0	35777·6 (3)		35960·0 (2)		36182·3 (2)	29422·0 (1)
$d\,{}^4\bar{P}_3$			35582·9 (4)		35805·5 (4)	29044·6 (1)
$d\,{}^4D_1$ 98·0	32825·2 (3)		* ?			
$d\,{}^4D_2$ 106·0	32726·9 (5*dv*)		32909·5 (3)		33131·9 (3)	26370·5 (0)
$d\,{}^4D_3$ 80·8			32803·6 (6)		33025·7 (4)	26264·7 (1)
$d\,{}^4D_4$					32944·9 (5)	
$d\,{}^4\bar{F}_2$ 145·2	34574·0 (0)		34755·4 (3*dr*)		34979·0 (1)	28217·5 (7)
$d{}^4\bar{F}_3$ 325·4			34611·2 (1)		34833·9 (1)	28072·3 (4)
$d\,{}^4\bar{F}_4$ 528·1					34508·0 (1)	
$d\,{}^4\bar{F}_5$						

* The line here is evidently masked by the strong line 33005·4 (4).

	$c\,{}^4\bar{D}_1$	144·2	$c\,{}^4\bar{D}_2$	249·7	$c\,{}^4\bar{D}_3$	337·3	$c\,{}^4\bar{D}_4$
$d\,{}^4\bar{P}_1$ 304·8	32840·3 (2)		32984·8 (2)				
$d\,{}^4\bar{P}_2$ 377·0	32535·5 (1)		32679·3 (3)		32929·1 (2)		
$d\,{}^4\bar{P}_3$			?		32553·3 (2)		32889·3 (4)

	$c\,^4\bar{D}_1$	144·2	$c\,^4\bar{D}_2$	249·7	$c\,^4\bar{D}_3$	337·3	$c\,^4\bar{D}_4$
$d\,^4D_1$ 98·0	29583·0 (0)		29727·7 (1)				
$d\,^4D_2$ 106·0	29485·2 (0)		29629·2 (2)		29878·9 (1)		
$d\,^4D_3$ 80·8			29523·2 (1)		29772·1 (2)		30109·3 (1)
$d\,^4D_4$					[29691]*		30028·8 (4)
$d\,^4\bar{F}_2$ 145·2	31330·5 (2)		31475·7 (3)		31725·6 (2)		
$d\,^4\bar{F}_3$ 325·4			31330·5 (2)		31579·7 (2)		31917·2 (2)
$d\,^4\bar{F}_4$ 528·1					31254·8 (6)		31592·2 (3*dr*)
$d\,^4\bar{F}_5$							31064·1 (8)

In addition to the quartet terms given before we also expect a number of doublet terms of slightly smaller value than the corresponding quartet terms of any particular combination. Though the existence of a number of other terms has definitely been established it has not yet been found possible to identify their natures unambiguously. In any case, no intercombination lines connecting quartet systems with doublets have been discovered. Pending further analysis these other terms have been designated variously as α, β, γ, ... in the list of classified Ne$^+$ lines which follows :—

Table of Classified Ne+ *Lines.*

λ	I	ν (Vac.)	Combination	λ	I	ν (Vac.)	Combination
2756·68	3	36264·8	$c^4P_2-d^4\bar{P}_1$	2876·41	3*dr*	34755·4	$c^4P_2-d^4\bar{F}_2$
2762·97	3	36182·3	$c^4P_3-d^4\bar{P}_2$	2888·39	1	34611·2	$c^4P_2-d^4\bar{F}_3$
2770·63	1	36082·3	$c^4P_1-d^4\bar{P}_1$	2891·50	0	34574·0	$c^4P_1-d^4\bar{F}_2$
2780·05	2	35960·0	$c^4P_2-d^4\bar{P}_2$	2897·03	1	34508·0	$c^4P_3-d^4\bar{F}_4$
2792·04	4	35805·5	$c^4P_3-d^4\bar{P}_3$	2910·11	2	34352·9	$c^4P_2-\gamma$
2794·22	3	35777·6	$c^4P_1-d^4\bar{P}_2$	2916·22	1	34280·9	$c^4P_3-\alpha$
2809·51	4	35582·9	$c^4P_2-d^4\bar{P}_3$	2925·66	2	34170·3	$c^4P_1-\gamma$
2858·02	1	34979·0	$c^4P_3-d^4\bar{F}_2$	2933·71	1	34076·6	$c^4P_3-\beta$
2869·93	1	34833·9	$c^4P_3-d^4\bar{F}_4$	2935·29	0	34058·2	$c^4P_2-\alpha$

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* There is a line 29689·3(6) which falls very near the line required here, but its intensity is so strong that it is probable that it comes from some other source and masks the line $c^4\bar{D}_3-d\,^4D_4$. The line 31330·5 occurs twice as $c\,^4\bar{D}_1-d\,^4\bar{F}_2$ and $c\,^4\bar{D}_2-d\,^4\bar{F}_3$, because $c\,^4\bar{D}_1-c\,^4\bar{D}_2=d\,^4\bar{F}_2-d\,^4\bar{F}_3=145$.

Table of Classified Ne+ *Lines*—(continued).

λ	I	ν (Vac.)	Combination	λ	I	ν (Vac.)	Combination
2951·15	1	33875·2	$c^4P_1-\alpha$	3334·89	10*R*	29977·4	$b^4\bar{P}_3-c^4\bar{D}_4$
2953·10	0	33852·8	$c^4P_2-\beta$	3344·44	5	29891·8	$b^4\bar{P}_1-c^4\bar{D}_1$
2955·77	7	33822·3	$b^4\bar{P}_3-c^4\bar{S}_2$	3345·88	1	29878·9	$c^4\bar{D}_3-d^4D_2$
3001·72	7	33304·5	$b^4\bar{P}_2-c^4\bar{S}_2$	3355·09	7	29796·9	$b^4\bar{P}_2-c^4\bar{D}_3$
3017·36	3	33131·9	$c^4P_3-d^4D_2$	3357·89	2	29772·1	$c^4\bar{D}_3-d^4D_3$
3027·07	4	33025·7	$c^4P_3-d^4D_3$	3360·63	5	29747·8	$b^4\bar{P}_1-c^4D_2$
3028·90	4	33005·7	$b^4\bar{P}_1-c^4\bar{S}_2$	3362·90	1	29727·7	$c^4\bar{D}_2-d_4D_1$
3030·82	2	32984·8	$c^4\bar{D}_2-d^4\bar{P}_1$	3367·25	6	29689·3	$c^4\bar{D}_3-d^4D_4$
3034·49	5	32944·9	$c^4P_3-d^4D_4$	3374·08	2	29629·2	$c^4\bar{D}_2-d^4D_2$
3035·95	2	32929·1	$c^4\bar{D}_3-d^4\bar{P}_2$	3379·34	0	29583·0	$c^4\bar{D}_1-d^4D_1$
3037·75	3	32909·5	$c^4P_2-d^4D_2$	3386·20	1	29523·2	$c^4\bar{D}_1-d^4D_3$
3039·62	4	32889·3	$c^4\bar{D}_4-d^4\bar{P}_3$	3390·56	1	29485·2	$c^4\bar{D}_1-d^4D_2$
3044·10	2	32840·9	$c^4\bar{D}_1-d^4\bar{P}_1$	3397·84	1	29422·0	$c^4\bar{S}_2-d^4\bar{P}_2$
3045·56	3	32825·2	$c^4P_1-d^4D_1$	3441·99	1	29044·6	$c^4\bar{S}_2-d^4\bar{P}_3$
3047·60	6	32803·2	$c^4P_2-d^4D_3$	3542·89	7	28217·5	$c^4\bar{S}_2-d^4F_2$
3054·70	5*dv*	32726·9	$c^4P_1-d^4D_2$	3551·52	1	28149·0	$c^4P_2-\delta$
3059·15	3	32679·3	$c^4\bar{D}_2-d^4\bar{P}_2$	3561·21	4	28072·3	$c^4\bar{S}_2-d^4\bar{F}_3$
3070·99	2	32553·3	$c^4\bar{D}_3-d^4\bar{P}_3$	3574·65	5	27966·8	$c^4P_1-\delta$
3072·68	1	32535·5	$c^4\bar{D}_1-d^4\bar{P}_2$	3594·15	2	27815·1	$c^4\bar{S}_2-\gamma$
3132·20	2	31917·2	$c^4\bar{D}_4-d^4\bar{F}_3$	3632·74	1	27519·6	$c^4\bar{S}_2-\alpha$
3151·12	2	31725·6	$c^4\bar{D}_3-d^4\bar{F}_2$	3659·91	2	27315·3	$c^4\bar{S}_2-\beta$
3164·42	3*dv*	31592·2	$c^4\bar{D}_4-d^4\bar{F}_2$	3664·05	9*R*	27284·5	$b^4\bar{P}_3-c^4P_2$
3165·68	2	31579·7	$c^4\bar{D}_3-d^4\bar{F}_3$	3694·19	10*R*	27061·8	$b^4\bar{P}_3-c^4P_3$
3176·14	3	31475·7	$c^4\bar{D}_2-d^4\bar{F}_2$	3709·66	7*R*	26949·0	$b^4\bar{P}_2-c^4P_1$
3190·86	2	31330·5	$c^4\bar{D}_1-d^4\bar{F}_2$	3734·94	7	26766·6	$b^4\bar{P}_2-c^4P_2$
3198·58	6	31254·8	$c^4\bar{D}_3-d^4\bar{F}_4$	3751·25	4	26650·2	$b^4\bar{P}_1-c^4P_1$
3218·22	8	31064·1	$c^4\bar{D}_4-d^4\bar{F}_5$	3766·28	8*R*	26543·9	$b^4\bar{P}_2-c^4P_3$
3232·38	3	30928·0	$c^4\bar{D}_1-\gamma$	3777·14	8*R*	26467·6	$b^4\bar{P}_1-c^4P_2$
3243·42	2	30822·8	$c^4\bar{D}_3-\beta$	3791·05	0	26370·5	$c^4\bar{S}_2-d^4D_2$
3248·16	3*dr*	30777·8	$c^4\bar{D}_2-\alpha$	3806·32	1	26264·7	$c^4\bar{S}_2-d^4D_3$
3263·40	2	30634·1	$c^4D_1-\alpha$	4224·57	1	23664·4	$\nu-c^4P_1$
3269·84	3	30573·7	$c^4D_2-\beta$	4257·25	1	23482·8	$\nu-c^4P_2$
3270·79	2	30564·9	$b^4\bar{P}_3-c^4\bar{D}_2$	4298·00	0	23260·1	$\nu-c^4P_3$
3297·74	8	30315·1	$b^4\bar{P}_3-c^4\bar{D}_3$	4377·95	2	22835·3	$\mu-c^4P_1$
3311·32	4	30190·8	$b^4P_2-c^4D_1$	4413·16	4	22653·1	$\mu-c^4P_2$
3320·28	1	30109·3	$c^4D_4-d^4D_3$	4457·04	4	22430·1	$\mu-c^3P_3$
3327·22	5	30046·5	$b^4\bar{P}_2-c^4D_2$	4569·02	5	21880·4	$\theta-c^4P_2$
3329·18	4	30028·8	$c^4D_4-d^4D_4$	4616·04	3	21657·5	$\theta-c^4P_3$

Further investigation is proceeding.

The author wishes to express his best thanks to Prof. M. N. Saha for his interest and guidance during the progress of the work outlined in this Paper.

Note added during correction :—After this Paper has been through the press, doublet terms have been identified. They will form the subject of a further communication.

XXXVI.—NEWTON'S LAW FOR THE EMISSION OF HEAT IN CARBON DIOXIDE.

By Sybil Marshall, *B.Sc., A.R.C.Sc., D.I.C.*

Received May 10, 1927.

Abstract.

This Paper is an extension of the investigation, started by the author and Mr. Vick, of the justification of employing Newton's Law of Cooling when estimating the external heat loss from the surface of a solid in a gaseous medium. In this case, the loss in a vertical system, containing in turn CO_2, oxygen and nitrogen, was examined, the apparatus consisting of compensated platinum wires mounted along the axes of ice-water cooled glass tubes and connected to the terminals of a Callendar-Griffiths bridge. The results show that, for tubes between 1 cm. and 3 cm. diameter, the law is applicable only as far as 10°C. for pressures between 1 atmosphere and 6 cm. mercury. The deviation above this temperature depends on the width of tube and the density of the gas, being greater for CO_2 than for oxygen or nitrogen.

Introduction.

In May, 1925, the author and Mr. Vick presented a Paper to this Society on "The Control Conditions under which Newton's Law is Valid for the Emission of Heat from Electrically-Heated Wires."(1) The experimental results were shown in the form of curves obtained by plotting the total wattage loss, C^2R_θ, against the temperature, θ, of the wire, keeping the pressure constant for each curve. A horizontal system of tubes containing air was used.

For investigating the heat transmission through carbon dioxide, the author had built a new system of tubes, arranged similarly to those described in the above Paper, but vertically disposed, in order to minimise the very large convective loss one would expect in this heavy triatomic gas. Another advantage that the vertical system had over the horizontal was that the ice and water thermostat(2) designed for this apparatus proved more efficient than the type used for the horizontal tubes.

Apparatus.

The apparatus consisted of two long and two short pieces of 4 mil platinum wire cut from the same specimen. Each of these was mounted along the axis of a lead glass tube by means of thicker platinum leading wires, one of each pair of leads being a spring to keep the fine wire taut. One long wire A and one short one B were enclosed in separate pieces of tubing of about 3 cms. diameter, and connected across the main and compensator terminals respectively of a Callendar-Griffiths bridge.(1), (3) The other long and short wires were mounted along 1·2 cm. bore tubing and connected similarly to another bridge, the wide and narrow systems being electrically independent, but in gaseous connection with each other. Both were connected to a pump and a CO_2 generating apparatus(2) and immersed in an ice and water thermostat.

Fig. 1 shows the vertical type of apparatus already described and used in the following investigation. The external leading wires are omitted from the diagram to avoid confusion. The electrical connections of one of the two systems are shown in Fig. 2. *A* and *B* represent the main and compensator wires, respectively, inserted in the arms of the Callendar-Griffiths bridge, each in series with a standard ohm, *S.R.* *P* is a potentiometer circuit connected across the terminals of the standard ohm in series with the main wire, and *E* is a series of rheostats in the main battery circuit, by means of which the current supplied by this circuit could be varied.

EXPERIMENT.

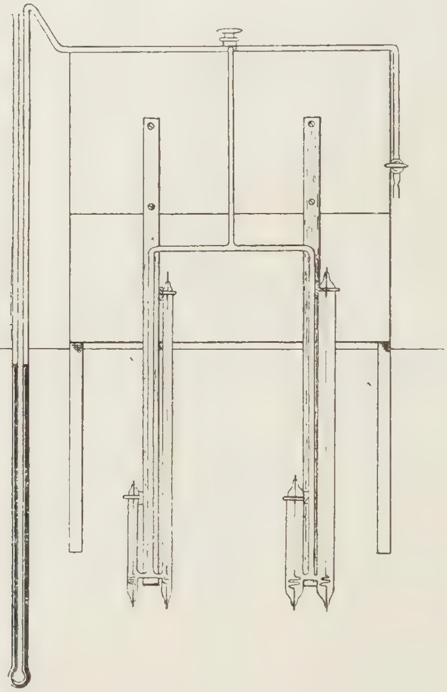

FIG. 1.—TUBES.

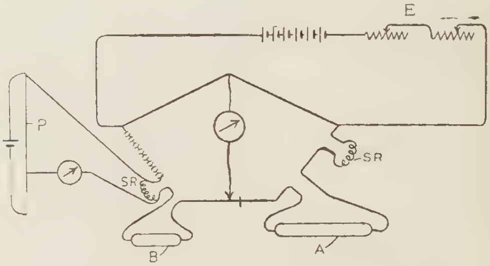

FIG. 2.—DIAGRAM OF CONNECTIONS.

The temperature range of the experiment extended between 0° pt. and 65° pt., the upper limit being the temperature corresponding to the maximum heating effect for which the bridge coils were designed. Starting with atmospheric pressure, and first using the wide system of tubes, the bridge was set at the highest temperature, the current in the battery circuit adjusted until a balance was obtained, and the current through the wires measured by means of the potentiometer across the terminals of the standard ohm in series with the main wire.(3) The wattage loss, $\frac{C^2R_\theta'}{100}$, could then be calculated for this temperature θ; C being the current in amperes and R_θ the resistance indicated by the bridge in cms. bridge wire, where 100 cms. bridge wire is equal to 1 ohm. The temperature of the wire was then dropped in a series of steps of 5° pt. and the current measured for each, keeping the pressure constant. A curve could then be plotted showing the relation between the heat lost by the wire and its temperature. The procedure was repeated using various pressures below atmospheric, and a set of constant pressure curves was obtained for this system of tubes. A similar set of readings was carried out for the tubes with the smaller diameter. The following results were obtained :—

Pressure, Cms. Hg.		I. 76·30		II. 62·60		III. 43·95		IV. 24·92		V. 6·15		VI. 0·20		VII. 0·0	
θ	R′	C	C^2R	C	C^2R_θ	C	C^2R_θ	C	C^2R_θ	C	C^2R_θ	C	C^2R_θ	C	C^2R'
			WIDE	TUBES.											
69·3	321·6											0·2731	23·98		
64·2	316·6	0·3122	30·82	0·3066	29·77					0·2810	25·00	0·2638	22·02	0·1488	7·00
59·1	311·6	0·2980	27·85	0·2938	26·90	0·2852	25·35	0·2740	24·40	0·2700	22·72	0·2540	20·10	0·1439	6·45
54·0	306·6	0·2851	24·90	0·2803	24·10	0·2724	22·75	0·2624	21·12	0·2584	20·47	0·2436	18·33	0·1386	5·88
48·9	301·6	0·2707	22·10	0·2656	21·28	0·2589	20·21	0·2498	18·80	0·2462	18·30	0·2326	16·32	0·1328	5·32
43·8	296·6	0·2550	19·43	0·2508	18·67	0·2447	17·78	0·2362	16·55	0·2334	16·17	0·2210	14·50	0·1264	4·74
38·6	291·6	0·2384	16·58	0·2350	16·10	0·2297	15·38	0·2223	14·41	0·2190	13·98	0·2085	12·68	0·1200	4·20
33·5	286·6	0·2217	14·10	0·2185	13·69	0·2138	13·09	0·2074	12·32	0·2054	12·09	0·1945	10·80	0·1127	3·67
28·4	281·6	0·2038	11·70	0·2008	11·37	0·1963	10·86	0·1911	10·28	0·1894	10·10	0·1802	9·15	0·1047	3·09
33·3	276·6	0·1852	8·92	0·1809	8·99	0·1768	8·64	0·1731	8·29	0·1717	8·15	0·1636	7·40	0·0953	2·51
18·2	271·6	0·1612	6·80	0·1593	6·89	0·1550	6·53	0·1530	6·36	0·1520	6·27	0·1451	5·72	0·0850	1·96
13·1	266·6	0·1358	4·92	0·1342	4·80	0·1310	4·58	0·1290	4·49	0·1291	4·46	0·1235	4·06	0·0720	1·38
8·0	261·6	0·1037	2·79			0·1020	2·72	0·1017	2·71	0·1010	2·67	0·0968	2·45	0·0569	0·85
			NARROW	TUBES.											
64·2	310·75	0·3136	30·60	0·3008	29·45							0·2817	24·63	0·1499	6·99
59·1	305·75	0·3003	27·63	0·2999	27·50	0·3038	28·20	0·2980	27·14			0·2714	22·51	0·1446	6·39
54·0	301·0	0·2858	24·60	0·2860	24·65	0·2880	24·98	0·2836	24·21	0·2810	23·77	0·2604	20·42	0·1392	5·83
48·9	296·0	0·2742	22·28	0·2705	21·68	0·2734	22·13	0·2694	21·50	0·2667	21·08	0·2487	18·30	0·1334	5·27
43·8	291·0	0·2580	19·39	0·2567	19·18	0·2560	19·10	0·2553	18·97	0·2539	19·05	0·2362	16·25	0·1274	4·72
38·6	286·0	0·2433	16·97	0·2420	16·75	0·2411	16·65	0·2406	16·57	0·2392	16·38	0·2234	14·28	0·1207	4 17
33·5	281·25	0·2282	14·64	0·2290	14·77	0·2260	14·38	0·2284	14·68	0·2238	14·10	0·2090	12·29	0·1136	3·63
28·4	276·25	0·2096	12·15	0·2089	12·07	0·2077	11·93	0·2072	11·86	0·2063	11·75	0·1935	10·35	0·1056	3·08
33·3	271·25	0·1903	9·83	0·1896	9·75	0·1887	9·65	0·1883	9·62	0·1874	9·52	0·1763	8·44	0·0964	2·52
18·2	266·5	0·1678	7·49	0·1679	7·51	0·1672	7·45	0·1668	7·42	0·1660	7·34	0·1564	6·52	0·0859	1·97
13·1	261·5	0·1424	5·30	0·1428	5·33	0·1420	5·28	0·1415	5·23	0·1408	5·18	0·1333	4·65	0·0735	1·41
8·0	256·5	0·1082	3·00			0·1107	3·15	0·1106	3·15	0·1101	3·11	0·1044	2·81	0·0576	0·86

Discussion of Curves.

It will be seen from the curves in Fig. 3 that for CO_2, even in a vertical system, convection was present to a considerable degree at temperatures above 10° pt. for tubes of about 1·5 cm. radius. This is shown by the fact that the curves corresponding to various pressures do not coincide above this temperature, as would be the case if conductivity, which is independent of pressure, alone were operative. For tubes of the above diameter, all curves corresponding to pressures down to 6 cm. mercury merge into the same straight line between 0° pt. and 10° pt., showing that for this region alone is Newton's Law obeyed. Here convection is absent, all the heat being carried by conduction, if we neglect radiation which is less than a half of one per cent. of the total heat loss. The dotted continuation of this straight line represents the variation with temperature of the heat lost by conduction over the whole temperature range of the experiment, and the difference between the ordinates of the total heat loss curve and those of the straight line give the heat lost by convection at any given temperature.* At the higher temperatures the curves diverge increasingly from the dotted line, the greater the pressure, the greater being the resulting increase of divergence with temperature.

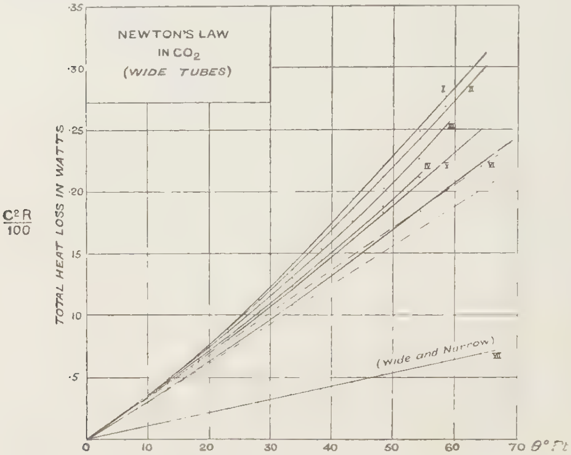

Fig. 3.

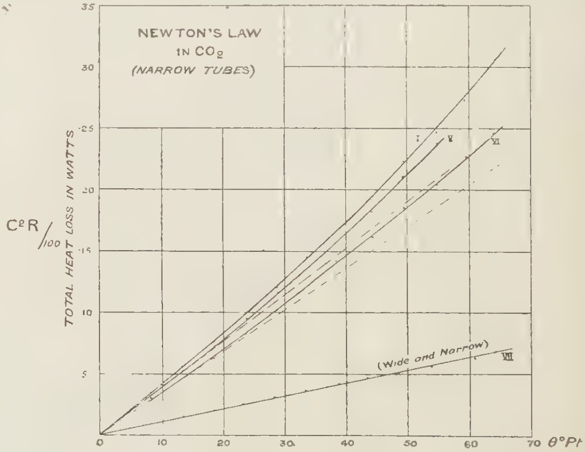

Fig. 4.

For the narrower tubes, whose radius was less than half that of the wide tubes, there was less convection. The curves are very much closer together, and they almost coincide with the same straight line up to a temperature of 20° pt. Above this temperature their divergence from one another increases very slightly, but there is a marked increase in their common divergence from their original direction. This tendency, which is also shown in the wide system, suggests that, even for a pressure of 6 cm. mercury, Newton's Law is valid only up to a temperature of 20° pt. for these tubes, on account of convection always being present at higher temperatures. Therefore, if one wishes to make use of the above law in estimating heat loss from surfaces in an undisturbed atmosphere of CO_2, these must be vertical, the distance from the hot surface to the cold not exceeding $\frac{1}{2}$ cm., and the limiting temperature difference is 20° pt.

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* That the heat lost by conduction is represented by the tangent at the origin to the total heat loss curve, is indicated by the fact that the slope of this tangent is independent of the pressure over the same range as that over which the conductivity is independent of pressure, and that both diminish as the pressure is lowered when the latter is less than 6 cm. mercury.

HEAT LOSS AT LOW PRESSURES.

When the pressure was reduced to 2 mm. mercury, the curve for each system tended to a straight line whose slope was less than that of the straight line to which the curves corresponding to the higher pressures approached,* and this straight line was different for each system. This change in the slope of the line, showing the variation of conductivity with temperature, is due to the fact that, at pressures where the mean free path of the molecules becomes comparable with the dimension of the tubes, conductivity no longer obeys Fourier's Law and ceases to be independent of pressure. At the above pressure the curve for the narrow tube is practically a straight line up to 50° pt., but for the wide the curvature becomes appreciable at 40° pt.

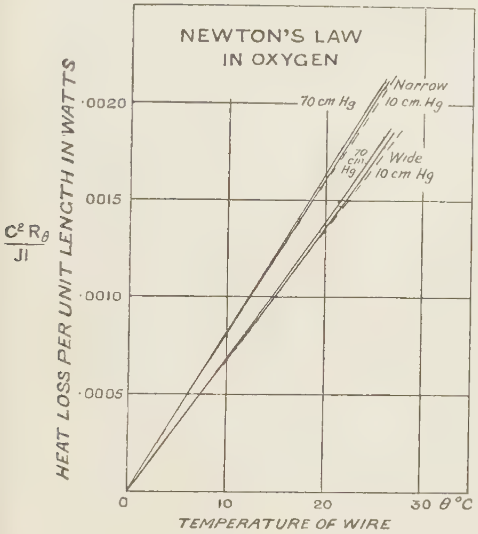

FIG. 5

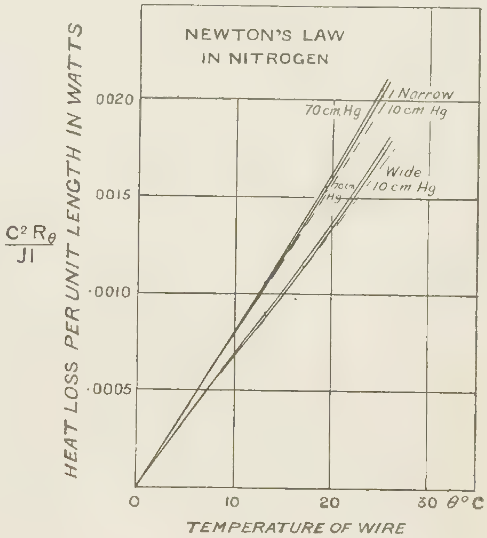

FIG. 6.

The only instance in which Newton's Law was obeyed over the whole temperature range and for both widths of tube was when the tubes were evacuated to the degree obtainable with a Gaede mercury pump. In this case the wattage/temperature curves for both tubes became one and the same straight line, whose slope was approximately one-third of the slopes of the two lines to which the two sets of curves tended for pressures above 6 cm. mercury, even though the curves for all pressures down to 2 mm. mercury tended to a different line for each set of tubes. Therefore, at this low pressure the heat transmission is independent of the distance between the hot and cold surfaces, showing that it is due to radiation and radiometer action⁽⁴⁾ alone. Newton's Law is never obeyed over an indefinite temperature range under the ordinary conditions necessary for conduction to take place according to Fourier's Law, where convection is bound to creep in as the temperature is raised and thus introduce a departure from the straight line law, but at low pressures where radiometer action occurs the law is obeyed and then only.

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* That the heat lost by conduction is represented by the tangent at the origin to the total heat loss curve, is indicated by the fact that the slope of this tangent is independent of the pressure over the same range as that over which the conductivity is independent of pressure, and that both diminish as the pressure is lowered when the latter is less than 6 cm. mercury.

NEWTON'S LAW FOR OTHER GASES IN A VERTICAL SYSTEM.

Dr. H. Gregory and the author having just completed their determinations of the thermal conductivities of Oxygen and Nitrogen, the latter made use of the results to draw curves showing the variation of the wattage loss per cm. of wire with the pressure of the gas in the tubes at constant temperature. From these were drawn wattage/temperature curves (Figs. 5 and 6) at constant pressure which, up to 10°C. and for pressures between 10 cm. and 70 cm. mercury, coincided with the same straight line whose slope depended on the diameter of the tubes, but was found to be approximately the same for the two gases on account of their thermal conductivities being nearly equal. Above this temperature a slight deviation from the original direction set in, which was more marked the higher the pressure. In the case of both gases at 25°C. this was between 3 and 4 per cent. of the total heat loss at that temperature for the wide tubes, and only 2 per cent. for the narrow. Below 10°C., therefore, one may disregard convective loss, which is represented by this deviation, for both widths of tube, and even up to 25°C., it is so small that one may safely assume Newton's Law for the heat transmission through Oxygen or Nitrogen in a vertical system, whose hot and cold surfaces are separated by a layer of gas not exceeding about half a centimetre at a pressure not appreciably above atmospheric.

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(1) Proc. Phys. Soc., vol. 37, part 5, p. 312 (1925).
(2) Roy. Soc. Proc., A., vol. 114, p. 354 (1927).
(3) Roy. Soc. Proc., A., vol. 110, p. 91 (1926).
(4) "Lectures on Theoretical Physics." H. A. Lorentz, p. 139.

XXXVII.—SOME EXPERIMENTS WITH SOUND WAVES OF HIGH FREQUENCY.

By S. R. HUMBY, *M.C.*, *M.A.*, The College, Winchester.

Received March 2, 1927.

(*Communicated by* PROF. E. V. APPLETON.)

ABSTRACT.

The interference and diffraction effects of sound waves of frequencies above 4,000 per second are studied quantitatively, using as detectors both sensitive flames and the ear.

A telephone energised by oscillatory currents produced by a thermionic tube circuit is used as a source of sound. This source has distinct advantages over other high pitch sources such as the Rayleigh bird call and other forms of whistle. Many of the experiments can be done with the sensitive flame fed by gas at ordinary pressures.

Two forms of sensitive flame are employed, one responding to points of maximum air density variation, and the other to maximum motion of the air.

The experiments on interference show results analogous to the optical interference experiments of Lloyd, Fresnel and Newton, and very close agreement is obtained between measured and calculated positions of points on the hyperboloid fringe systems. An experiment is described in which results analogous to certain Heaviside layer effects are obtained.

Diffraction near various obstacles and a sound zone plate are studied.

Some observations are recorded on the fatigue of the ear and binaural audition.

THE Papers of the late Lord Rayleigh contain details of numerous experiments made with high frequency sound waves and in these experiments the acoustic analogies to many well-known experiments in optics were examined.

The present Paper gives details of a repetition and extension of these experiments in which use was made of a different type of source of vibration.

Rayleigh used as his source a " bird call " or whistle of very high pitch. Experiments with this instrument for use in lectures showed that it is not an easy piece of apparatus for anyone whose laboratory equipment does not include a blower by which steady air pressure can be obtained.

It was therefore decided to test the possibilities of a telephone receiver placed in the plate circuit of a three electrode vacuum tube which was producing oscillatory currents of the desired frequency. This arrangement has the great advantage that its frequency is regular and is under control. Also the intensity of the sound can be varied by means of a resistance box used to shunt the telephone earpiece.

A coil of 1,500 turns of insulated wire was wound with mean diameter about 3 inches. This formed the inductance of the circuit which was completed as shown in Fig. 1.

A variable condenser of about 0·01 microfared maximum capacity was used to tune the telephone note.

The circuit used gives frequencies between 4,000 and 16,000.

A sensitive flame was used as a detector aided occasionally by the ear.

The results obtained were in most cases very definite, and this form of telephone whistle is recommended to anyone who wishes to perform with the minimum of trouble the very beautiful experiments on interference. These can be done for frequencies below 12,000 without the use of a high pressure flame, so that they are within the power of anyone who uses the valve circuit.

In making the sensitive flame jets it is best to draw out several from fairly wide bore (1 cm.) glass tube and to test each on the ordinary gas pressure. If the flame roars, its pressure can be reduced by the use of a screwcock until it is just silent. If the jet is of any use, it will now respond to an *S* sound.

An opening 0·1 cm. diameter is about right, and the jets can be adjusted by means of an ordinary glass file.

Two Forms of Sensitive Flame.

It was found that the flame could, with sounds of certain frequencies, be adjusted to one of two sensitive states. As one of these appears to be unknown to many experimenters, it may be of interest if details are given.

The more usual form of sensitive flame is obtained when the flame is just not roaring. Then, when the source of high pitch sound is switched on, the long silent flame drops to form a short noisy one, of which the behaviour has been described in detail in Tyndall's Sound.* Measurements of the positions for which the flame roared and was silent when stationary waves had been produced in front of a reflecting surface, showed that† the flame is most affected at a loop or antinode. On the other hand, it was found that in some cases, if the flame is first adjusted until it is rustling but not roaring loudly when there is no sound, then the switching on of the whistle causes the flame to become quiet and longer than before. When this type of flame was used to explore the stationary waves in front of a plane mirror the positions of least movement of the flame were such that this flame was silent at a loop of the stationary wave system. The coal gas pressure used for both of these flames was about 8·6 cms. of water.

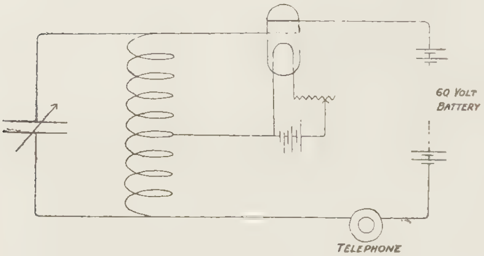

FIG. 1

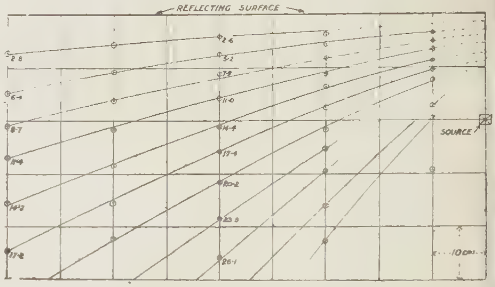

FIG. 2.—REFLECTION AT A PLANE MIRROR. WAVE LENGTH 2·9 CMS. PATH DIFFERENCES MEASURED IN CMS. ARE SHOWN.

Two sets of measurements are given later.

Measurements of the exact positions of interference and of diffraction fringes were made easier by mounting the stand carrying the sensitive flame on a small trolley fitted with rubber wheels. When this was done, the flame could be moved from place to place very smoothly so that it did not roar owing to mechanical vibration.

In the experiments, a high pressure flame was rarely used, because the gas reservoir available only maintained the flame at pressures of 25 cms. of water for about 5 minutes, and this made the location of a field of fringes a very tedious business. Most of the measurements were therefore made with the reservoir connected to the ordinary supply mains. These supplied the gas at about 10 cms. of water which, by choice of a suitable jet, gave very good results for sounds up to a frequency of 11,000. The wavelength so obtained (3 cms.) is short enough to show quite sharply defined shadows.

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* Pp. 232 to 240.

† As Rayleigh states, Phil. Mag., page 153 (1879).

The range of frequencies to which a jet responds is often very small—in one case 5 separate responses were measured between 4,260 and 4,640.

The sensitiveness, as other experimenters have pointed out, varies very much for disturbances of the same frequency coming from different directions.

With jets on which measurements were made, it was found that the frequencies of response were unaffected by small changes of gas pressure, although the sensitiveness fell off rapidly as the pressure was lowered from the critical stage at which continuous roaring begins.

Measurements were made to see if any simple relation exists between the various frequencies to which a given jet responds. The following are the records for 4 different jets showing the frequencies to which each responded :—

(1) 11000, 7610, (7100), 6600, (6000), 4450, 4000.
(2) 7610, 6470, (6000), 4390.
(3) (7400), (6530), 4640, 4520, 4400, 4350, 4260.
(4) 10600, (10000), 7800, 7100, (6470), 4550.

The frequencies in brackets gave much weaker effects on the flames.

EXPERIMENTS ON THE REFLECTION OF SOUND.

Reflection of the higher pitch sounds, particularly of those just audible to the average person, can be shown very well across a large lecture room by using the ordinary metal mirrors supplied for experiments in sound and in the radiation of heat. These give a very sharply defined beam of sound which can be focussed by another mirror on a sensitive flame at considerable distances. Very useful cylindrical mirrors of large aperture can be made at negligible cost from a large sheet of thin three-ply wood bent to a convenient shape by means of two pieces of cord.

Thin three-ply wood was also used to make a lecture table " whispering gallery " by which the creeping of the sound waves along the surface can be shown and the way in which the disturbance is cut off by an obstacle placed against the wall but is unaffected by obstacles some inches away from the face of the gallery.*

In this experiment use can often be made of the relative insensitiveness of the flame to sounds coming from certain directions.†

INTERFERENCE EFFECTS DUE TO STATIONARY WAVES FORMED BY REFLECTION.

The positions of the nodes of stationary waves formed in front of any reflecting surface are very clearly marked when the telephone whistle is used. The measurement of consecutive positions of minimum flame disturbance in front of a plane mirror gives the most convenient way of determining the wavelength and the frequency of the sound. Two sets of such measurements illustrate the difference between the two types of sensitive flame already mentioned.

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* Raleigh, Proc. Roy. Inst., Jan. (1904) ; Bragg, World of Sound, p. 84.

† Bragg, p. 26.

Using the ordinary type of flame the positions of least disturbance in front of a plane mirror were

2·1, 4·1, 6·3, 8·3, 10·9, 12·6, 14·7 cms.

These are in the ratio 1, 2, 3, 4, 5, 6, 7.

If the loops had been points of least disturbance the series would have been 1, 3, 5, 7.

With the other sort of flame a set of readings for least disturbance were 2·2, 3·6, 5·2, 6·6, 8·1, 9·5 cms. Here the ratios are 3, 5, 7, 9, 11, 13, showing that the positions of least disturbance of the flame corresponded to the position of loops of the stationary wave system.

It is interesting to hear the variations of loudness of sound throughout a room when the note is switched on. The room is found to be filled with stationary nodes and loops, for, as the ear is moved, the sound wells out and diminishes in a fascinating way. This is best tested at first by holding a pad over one ear ; the other ear will then be able to pick up more easily the stationary fringes in front of any wall. It was found that with the one-valve circuit used and 60 to 200 volts high tension the stationary waves could be located by a sensitive flame at distances up to 15 feet from the source and for several feet from the particular reflecting surface, especially when beams of sound were obtained by the use of large curved mirrors. An additional valve amplifying circuit gave, of course, a great increase of intensity of sound.

" LLOYD'S MIRROR FRINGES " AND " CIRCULAR FRINGES."

Measurements were made of the interference system formed by placing the source in front of a large plane surface.

The points of maximum and minimum disturbance of the flame were very sharply defined.

A scale diagram is shown for wavelengths of 2·9 cms. (Fig. 2). It will be noted how well the measured path differences to various points agree with the theoretical values.

AN ACOUSTIC ANALOGY TO CERTAIN " HEAVISIDE LAYER " EXPERIMENTS.

Professor Appleton pointed out to me that the interference experiments with short sound waves should give an illustration of certain effects which were recently made use of in an investigation of the reflection of wireless waves from the Heaviside layer.* In the experiment wireless waves of constant amplitude transmitted from Bournemouth, or from Teddington, were received near Peterborough. When the wavelengths of the transmitted signals were continuously varied the amplitude of the received signals passed through a series of maxima and minima owing to interference between the ground waves and those reflected from the Heaviside layer, of which the height could then be found. The analogous effect with sound waves can be well shown if a sensitive flame jet is chosen so that the sensitiveness is fairly uniform over a range of frequencies.

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* E. V. Appleton and M. A. F. Barnett, " On Wireless Interference Phenomena between Ground Waves and Waves deviated by the Upper Atmosphere." Proc. Roy. Soc. A, Vol. 113. (1926).

The flame was placed one or two feet from a vertical wall and the whistle, frequency 5000, was placed about an equal distance from the wall and six feet from the flame. When the capacity of the circuit was slowly and continuously increased by 0·001 microfarad the flame recorded 16 maxima and minima. The tuning for the points where the flame was long and silent was extremely sharp so that very steady variation of capacity was required to make the changes of intensity clearly visible.

FRINGES FROM TWO SOURCES.

Two telephones in the same circuit give rise to a family of hyperboloid fringes and again the positions are very clearly defined. As the two sources are usually of different sensitiveness the best results are obtained by using a high adjustable resistance to shunt the windings of the louder earpiece.

A scale diagram is given with measured path differences to certain points (Fig. 3).

This arrangement of two telephones forms an impressive demonstration since the sensitive flame can be shown roaring violently under the influence of one source placed a few inches from it. Then, as the other telephone is brought up, the flame passes through alternate states of disturbance and quietude, and it can finally be left motionless and undisturbed while the two telephones are fixed an inch or two away on either side and the whole room is filled with the whistling sound.

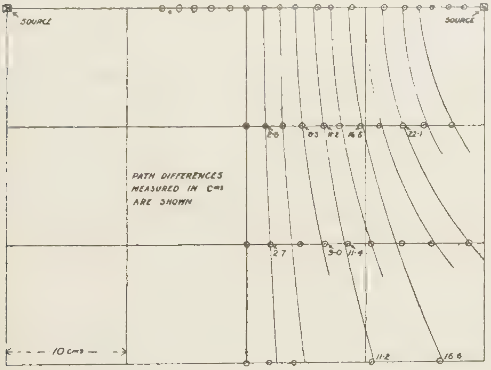

FIG. 3.—INTERFERENCE FRINGES DUE TO TWO SOURCES 40 CMS. APART. WAVELENGTH 2·8 CMS.

DIFFRACTION EFFECTS.

It is found that the ordinary diffraction effects can be shown well over a large frequency range, using telephone whistles. With a slit 20 cms. wide by 43 cms. high, and a source 40 cms. away, a central maximum and several side maxima could be measured at 40 cms. beyond the screen (Fig. 4).

The diffraction of the waves round an obstacle (a long rectangular board 23 cms. wide) gave a sharply defined " bright spot " on the line joining the source to the centre of the obstacle and a number of minima outside the geometrical shadow. In these experiments 3 cms. waves were used.

In a similar way the zone of disturbance at the centre of the shadow of a circular disc can be shown. A glass disc 33 cms. diameter, cut for a Wimshurst electrostatic machine, was used as the obstacle. With the source 50 cms. from the disc the central spot and two other zones could be detected within the geometrical shadow and one outside it. The wavelength was 4·4 cms.

THE ZONE PLATE.

A zone plate was cut out of thick cardboard with the inner circle of radius 7·7 cms. and the other rings with radii in the ratios of the square roots of 1, 2, 3, 4, 5, etc. Using waves of 4·4 cms. with the source 30 cms. and the flame 17 cms. from the zone plate it was easy to show that the disturbance was very strong with the central zone out and was much less with the second zone also removed. It was definitely greater again when the third zone was removed and still more vigorous with zones 1 and 3 out and with 2 replaced. The removal of other alternate zones seemed to have no marked effect presumably because of the obliquity of diffraction from them. The length along the axis over which the disturbance seemed to be a maximum was about 1 cm. The distance of the source and flame enable us to calculate the first focal length of the zone plate.

Thus, $$1/(-17)-1/30=1/f,$$

and $$f=-11 \text{ cms.}$$

The simple theory gives the focal length as—

$$f=-\frac{(\text{Radius of inner ring})^2}{\text{wavelength}}$$

$$=-\frac{(7{\cdot}7)^2}{4{\cdot}4}=-13 \text{ cms.}$$

With shorter waves we get, as we might expect, a closer agreement between the observed and the calculated values. When the wavelength was 2·95 cms. and

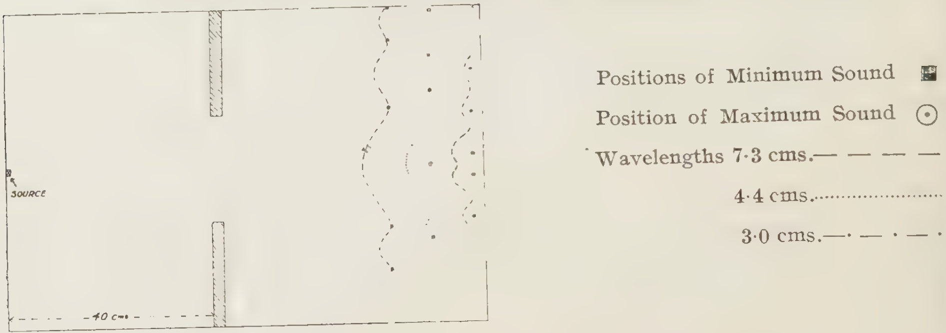
SOURCE
40 cm
Positions of Minimum Sound ▪
Position of Maximum Sound ⊙
Wavelengths 7·3 cms.— — — —
4·4 cms.........................
3·0 cms.—· — · — ·

FIG. 4.—DIFFRACTION THROUGH A RECTANGULAR APERTURE.

the source was distant 30 cms. the point of maximum disturbance was 57 cms. beyond the zone plate. This gives $f=-19{\cdot}7$ cms., and the calculated value for this wavelength is 20·1 cms.

DIFFRACTION AT A STRAIGHT EDGE.

Diffraction effects could be detected round the edge of a large wooden screen. The gradual and progressive weakening of the effect on the flame as it passes into the geometrical shadow is well shown and the presence of variation of intensity outside the shadow.

THE DIFFRACTION GRATING.

An attempt was made to construct a diffraction grating by means of cardboard strips fastened across a rectangular opening in a large screen. There were nine openings, each 3·4 cms., with the strips 1·7 cms. wide. The source was placed at the focus of a metal mirror 80 cms. from the grating. The frequency used was

11,600. With the flame 70 cms. behind the grating a set of interference fringes were found. They were spaced almost regularly at intervals of 9·2 cms. These positions were all confirmed by using a long rubber tube with its other end placed to the ear. No appreciable difference of intensity was noted among these positions. The use of the tube is not very comfortable or convenient. Only in a few cases can the unaided ear be used satisfactorily in quantitative observations, as usually the presence of the head causes too great a disturbance of the field of sound. When the ear is used as a detector it hears most sound where the density variations are greatest.* Therefore, its maxima coincide with points of quietude when use is made of the ordinary type of sensitive flame, and to places of maximum disturbance of the other form.

FATIGUE OF THE EAR.

Lord Rayleigh† records that for sounds of very high pitch the ear becomes insensitive after three or four seconds, and that a momentary screening of the ear by the hand allows the ear partially to regain its power of hearing the whistle. I cannot detect in my own case any variation whatever in the loudness of the sound heard.

When I can hear the sound (up to about 14,000) I find no appreciable fatigue even over long intervals. The head must, however, be kept quite still, because a movement through one centimetre may take the ear from a point of sound to one of silence. Experiments with a number of observers showed that while some noted no fatigue, others stated that the audibility diminished rapidly, but became temporarily greater again on moving the head.

BINAURAL AUDITION.

In accordance with a suggestion made by Professor E. V. Appleton, I have adjusted two high-frequency oscillators to give beats with one telephone earpiece in each circuit. This made possible a repetition at a high frequency of one of the experiments performed by H. Banister on the effect of binaural phase differences on the localisation of tones.‡

In an early experiment with frequencies about 5,500 it was possible to adjust the beats to keep steady with frequencies down to three per second. Further adjustment then brought the two notes into unison. The notes remained in unison for a certain range of condenser variation in either circuit, this range being less when the degree of coupling between the two circuits was decreased. With weaker coupling between the two circuits the beats could be brought as slow as one in two seconds before the circuits "locked" into unison. It has been shown that the variation of capacity from one side of the unison range to the other is accompanied by changes in the relative phases of the two oscillations, which are in phase for one position, and have a phase difference of 180° at the other.§

Visual evidence of this phase change was obtained by arranging two telephone receivers, one in each circuit, about 3 ft. apart with a sensitive flame somewhere in their neighbourhood. When the telephones were producing sounds of slightly different pitch the disturbances of the flame kept time with the audible beats. The two circuits were just brought into unison so that the beats ceased and the flame was moved to a position either of maximum or of minimum disturbance in the interference system produced. When the flame was quiet a slow change of the capacity of either circuit caused the flame to commence to roar as the condenser reading approached that which corresponded to the other limit of the unison adjustment, showing that the vibrations of the two telephone diaphragms had altered in phase through 180°. The use of a tube leading to the ear showed a corresponding change at any point from a maximum to a minimum of sound.

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* Rayleigh, Sound, Vol. 2, p. 77.

† Phil. Mag., p. 344 (1882).

‡ British Journal of Psychology, 15, p. 281, Jan. (1925); *see* also Phil. Mag., Vol. 2, July (1926) and August (1926).

§ E. V. Appleton, Proc. Camb. Phil. Soc., 21, p. 231 (1922), and H. Banister, *loc. cit.*

It is hoped in a further Paper to describe other experiments in connection with the binaural effect at both high and low frequencies.

Attempts are also being made to obtain visible sound fringes with a view to the possibility of photographing the effects so far obtained.

The author desires to thank Professor Appleton for the above suggestions and for his encouragement, and Mr. Abley, of the College Laboratory, for his assistance in the construction of the necessary apparatus.

DISCUSSION.

Dr. D. OWEN: I should like to congratulate the author on an interesting series of experiments. The thermionic oscillator places at our disposal a steady source of sound of constant frequency, and the diaphragm of a telephone serves as a sufficiently small vibrating source to permit of a very beautiful and instructive series of experiments illustrating interference phenomena. The Paper contains two novel points. In the first place the discovery that under certain conditions a low-pressure sensitive flame indicates the points of maximum pressure variation in a stationary system of waves, in contrast with the usual high-pressure sensitive flame which indicates the points of maximum particle displacement. In the second place the conclusion is drawn that the low-pressure flames are sensitive only to certain frequencies. These are observations which merit fuller investigation. In regard to the second it should not be overlooked that with a given telephone diaphragm actuated by a valve oscillator whose frequency is gradually varied, the intensity of the emitted sound rises and falls very markedly as the frequencies of natural vibration of the diaphragm are in turn passed through. Before the author's conclusion that the flame itself is selective can be accepted this factor must obviously be eliminated. I should be interested to know whether the author had succeeded with this type of sound source in actuating Kundt s tube. Such a means would be a welcome substitute for the rod excited by stroking.

Prof. A. O. RANKINE suggested that the Doppler effect might be demonstrated by a change in beat frequency when one of two simultaneously sounding telephones is moved towards or away from the flame.

This experiment was accordingly tried with success.

Dr. J. H. VINCENT: The author has added greatly to his interesting and important Paper by the successful demonstration which followed it. Has Mr. Humby tried different types of telephone receivers? I have found that an instrument of the reed type has the useful property of acting as a source of high frequency sound when in the alternating magnetic field of a valve oscillator, even when unprovided with leads. As one can alter the intensity of the sound emitted by the telephone by changing its orientation with respect to the oscillator coil, the intensity can be adjusted to equality with an independent source; under these conditions beats can be obtained of surprising distinctness. I was interested to notice that the author in one of his experiments employed the automatic synchronisation of two valve oscillators which were first shown to the Physical Society in 1920.* This phenomenon provides a simple means of producing a high-frequency rotating magnetic field which perhaps would be useful in studying the gyromagnetic effect.

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* Vincent, Proc. Phys. Soc., p. 84 (1920).

Mr. W. E. Benton said that the author might find it convenient to control the gas pressure by means of a governor of the kind used by gas companies; this would keep the output pressure constant to about 2 per cent. for a 100 per cent. increase in the input pressure. An extremely delicate means for measuring small variations in amplitude was afforded by the pin-hole probe of Prof. Carl Barus. Owing to the flange which is formed in piercing a pinhole in a sheet of metal, the hole acts as a rectifier of sound waves, and when sound falls on it a difference in pressure is set up between the two sides of the sheet. This difference can be measured with a precision of 10^{-6} mm. of water by means of the interference manometer, in which a glass plate floats on the mercury in each limb of a manometer U-tube, relative changes in level of the glass plates being measured by means of an interferometer. This arrangement has been employed in the study of the amplitude of vibration in organ pipes.

Prof. O. W. Richardson said that Dr. Vincent's arrangement for producing a high-frequency rotating field had been used by Mr. Fisher, of King's College, in experiments on the gyro-magnetic effect.

Author's reply: I have attempted to use the telephone whistle on a Kundt's tube, but so far the power available had not been sufficient to disturb the lycopodium powder. With regard to the possibility of apparent flame selectivity being due to the variation of amplitude of the motion of the telephone diaphragm, I feel that the figures given in the Paper show that variation of output cannot be the chief cause of selective response. The figures are for different flame jets with the same telephone as transmitter, and there were no frequencies common to all the jets. There should be if variation of output were the most important factor in determining the frequency at which response of the flame was obtained.

Prof. Rankine's suggestion for the demonstration of the Doppler effect by a change in the observed beat frequency when one of the oscillators is moved relative to the flame, gives an experiment similar to that in which one of two slightly mis-tuned tuning-forks is moved relative to the other. In either experiment the change of beat frequency can be heard, and can be rendered visible by the motion of a suitably chosen sensitive flame.

Dr. Vincent's observation of the effect of high-frequency induction effects on telephone receivers is of interest. I have only used about half a dozen different receivers, and all were of the ordinary diaphragm type. I also have noticed the surprising distinctness of the beats obtained when the two independent sources are carefully adjusted to equality of output by the variation of a high resistance placed in parallel with the louder telephone whistle.

A gas governor of the type referred to by Mr. W. E. Benton should make it easier to carry out a series of measurements of stationary interference fringes. I had to be content with an improvised "gasometer" connected direct to the supply mains. For demonstrations, however, it was sufficient to use the gas direct from the mains, provided the jets were adjusted for the pressures which were available.

XXXVIII.—SOME ADDITIONAL REFINEMENTS FOR PRECISION BALANCES.

By J. J. Manley, *M.A.* (Fellow of Magdalen College, Oxford).

Received March 16, 1927.

ABSTRACT.

This Paper deals with certain small errors attendant upon the use of the rider of a precision balance, and shows how such errors may be rendered negligible. Attention is also drawn to some disadvantages resulting from the employment of velvet-covered pan arrestors and a plan is described for eliminating them.

In former Papers* certain devices for ensuring high precision in weighing have been described. In this Paper is given an account of some additional refinements whereby the attainment of still greater precision is rendered possible.

The need for the new refinements was brought into prominence by the requirements of a recent problem for the solution of which it was necessary, amongst other things, to determine with considerable accuracy masses of less than 0·3 mg. To improve upon the refinements already in use was more than a little difficult; hence attention was centred chiefly upon the rider and the manner of using it.

The scale for the rider is usually engraved upon the beam itself: but in some cases it is cut upon an attached thin strip of metal. The upper surface of a balance beam is often flat and less frequently bevelled. A bevelled beam is either graduated or more generally serrated. In the case of the flat top, the position of the rider is ascertained by a scale cut upon the face of the beam: and, provided due care be observed, the plan is for most purposes sufficiently accurate. It may, however, be noted that we here assume that the crown of the placed rider is a horizontal right line running strictly perpendicular to the length of the beam. In general the crown is neither perfectly straight nor placed with the theoretical accuracy supposed. Errors arising from these two defects are likely to be more definitely marked in a beam that is flat than in one that is serrated. In the case of the latter they become vanishingly small when the bevel is acute and the serrations shallow and geometrically correct. But when a beam having a flat top is used and a series of rider settings of one and the same indicated value carried out, we find that successive resting-point determinations, instead of being invariable, differ very appreciably. Hence for high accuracy we must, under these circumstances, adjust the rider and determine the corresponding resting-point a number of times and accept the mean value as the best available.

Another and not readily suspected source of error arises from a want of strictly accurate spacing of the scale divisions or the serrations, as the case may be. In illustration of this the results obtained by calibrating the beams of two high-grade balances with micrometers may be quoted. One beam was flat and the other serrated. In the first case the extreme difference in the spacing was 8·2 per cent.

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[*] Phil. Trans. Series A, Vol. 210, p. 387, and Vol. 212, p. 227. Also Proc. Roy. Soc. A, Vol. 86, p. 591. Article "Balance" Thorpe's Dict. of Chem. New Edition.

and in the second 0·8 per cent. Expressed as possible variations in weight, these errors are respectively ·085 and ·008 mg. These several errors were minimized in the following way.

First, to each end of the beam and at the back of it was attached by means of screws, as shown in Fig. 1 *a*, an L-shaped plate of aluminium. Next, two riders, having the form shown in Fig. 1, *b*, were made and their flat ends perforated. One was of gold and the other of aluminium ; the first weighed 10 and the second 1 mg. After the riders had been adjusted, a platinum wire 0·1 mm. in diameter was drawn through each ; the two wires were then passed through holes pierced in the L-shaped plates, drawn taut and secured as depicted in Fig. 1.

For moving the riders it was necessary to construct and substitute another apparatus for that commonly used ; an end-on view of this is seen in Fig. 2. In the figure, *A* is a stout brass plate drilled for the reception of the tube used for operating it, and ω_1, ω_2, are two platinum wires 0·2 mm. thick, fixed and bent as shown. The relative positions of the two riders r_1, r_2, upon their wires are also shown. The movements of the stops s_1, s_2, about the centre *c*, are limited by a glass surface *f*, *g*. This limitation guards the stretched wires against undue pressure from ω_1 and ω_2. By suitable horizontal and rotational movements of the plate *A*, the wires ω_1, ω_2, can be brought to bear against either face of the corresponding rider : and then by pushing or pulling, as the case may be, the rider can be moved to any point of the supporting wire.

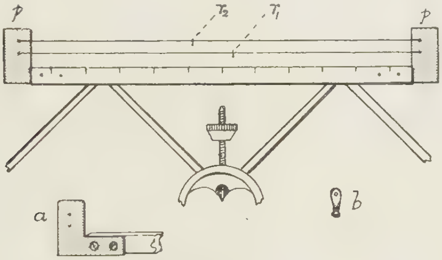

FIG. 1.

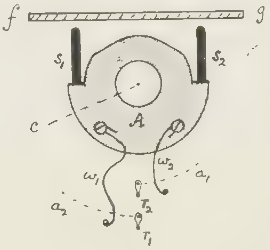

FIG. 2.

When the changes just described had been completed, it was no longer possible to stabilize the beam. This difficulty was overcome by removing one-half of the gravity bob from its normal position above the centre of the beam to the upper portion of the pointer upon which a fine thread had been cut for it. Thus the balance now possessed two gravity bobs, the one above and the other below the central knife-edge : by adjusting these any required sensitivity could again be obtained. We now consider the methods used for accurately determining any position occupied by a rider.

As it was obviously impossible to locate a rider with any degree of precision by using the beam scale alone, a large reading-telescope mounted upon a travelling platform *P*, as shown in Fig. 3, was employed. The platform was provided with three contacts, which consisted of two brass balls at the back and a wheel, seen in front. The balls rested within a lubricated and rigidly fixed V-groove and the wheel upon a flat surface. The telescope was set up at right angles to the balance, and therefore when the handle *H* was turned the screw *s* moved the platform in a direction parallel to the sighted beam. The traverse of the telescope was somewhat greater than the length of the beam: hence any part of the scale could be brought under observation.

When using this apparatus in connection with weighing, the simplest plan is first to move the 10 mg. rider until equilibrium is approximated, and then to obtain a sufficiently close approach to equality by moving the 1 mg. rider. The resting-point is then determined, the beam arrested and the telescope moved along until its fine vertical cross-thread coincides with, or rather covers, the thin edge of the sighted rider, the position of which is then noted. As will be seen, the position of the riders are in this way determined only with the usual degree of precision. The system does, however, offer two advantages. First, as the rider cannot be dropped, possible damage and loss are eliminated. Secondly, the position of the rider is defined with great exactness, and its contact is equivalent to a fine line drawn at right angles to the supporting wire. If by chance the eye of the rider is larger than it should be, the rider will at times rest slantwise; but in that case it can at once be correctly orientated by lightly tapping the stretched wire with the rider apparatus. The plan introduced for measuring the position of a rider with increased accuracy may now be described.

On referring to Fig. 3, it may be seen that a tangent screw *t* by which the telescope may be slightly rotated about its vertical axis is equipped with a head *k* and an index *i*. The index is more clearly seen in Fig. 4, wherein is also shown a metal arc *a* graduated in mm. The distance from the balance to the telescope was 225 cms. Under these circumstances, the coincidence of the cross-thread was transferred from one minor division of the beam to the next, when the index was moved over an arc of 42 mm. The accuracy with which the position of a rider was determinable had thus been increased from an *estimated* 1/10 to a *measured* 1/42 of a minor division of the beam.

The arms of the balance under discussion were each divided into 50 parts, and so for the two riders each division corresponded to the respective values of 1/5 and 1/50 mg. Hence, by the device of the tangent screw, the accuracy with which any positional value could be measured was respectively $1/5 \times 42$ and $1/50 \times 42$ mg. The advantage thus gained was utilised by means of the following optical method.

First the central knife-edge block was drilled and one end of a fine aluminium tube inserted and secured. Into the other end of the tube, which was centred in a small opening cut in the beam case,* was thrust a wire supporting a flat palladium mirror. The mirror, which was adjusted vertically, faced a window of parallel-plane glass set slantwise† in one end of the balance case. Opposite the window, and at a distance of 125 cm. from it, was a powerfully illuminated and perpendicular mm. scale. For viewing the image of this scale, a second reading telescope was directed towards the mirror and fixed at a distance therefrom of 3 M. As the effective length of the pointer of light was 6 M, and that of the ordinary pointer 30 cm., the accuracy with which a deflection of the beam could be read was thus increased twentyfold.

When the additional arrangements had been completed and the balance adjusted to a high sensitivity *S*, it was found that the resting-point changed by 300 units‡

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* Phil. Trans. A. Vol. 210, p. 407.

† Multiple images were thus avoided.

‡ The unit was 1/10 mm.

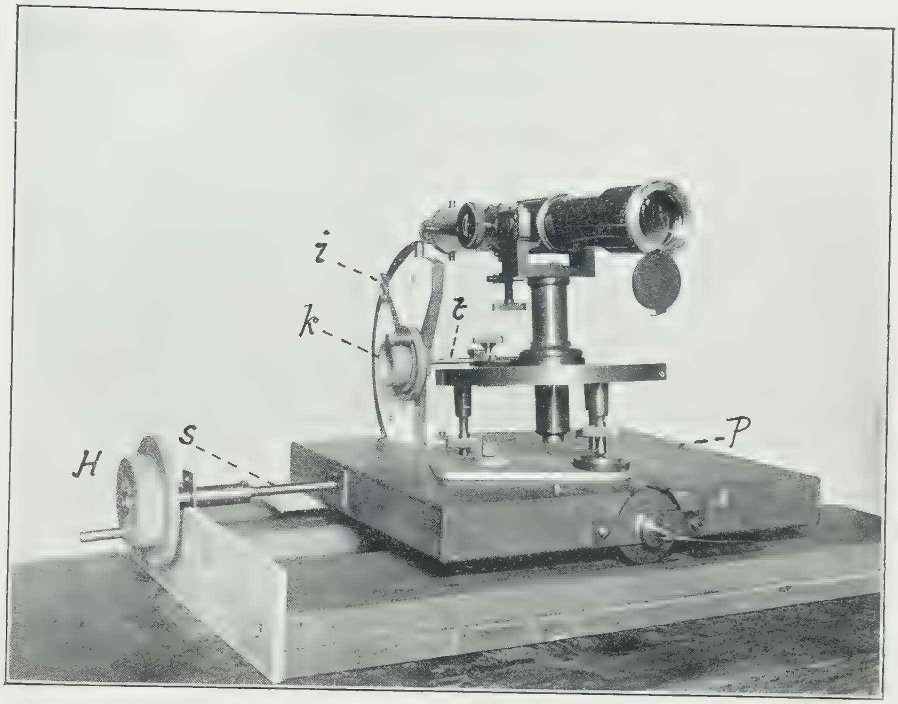

FIG. 3.

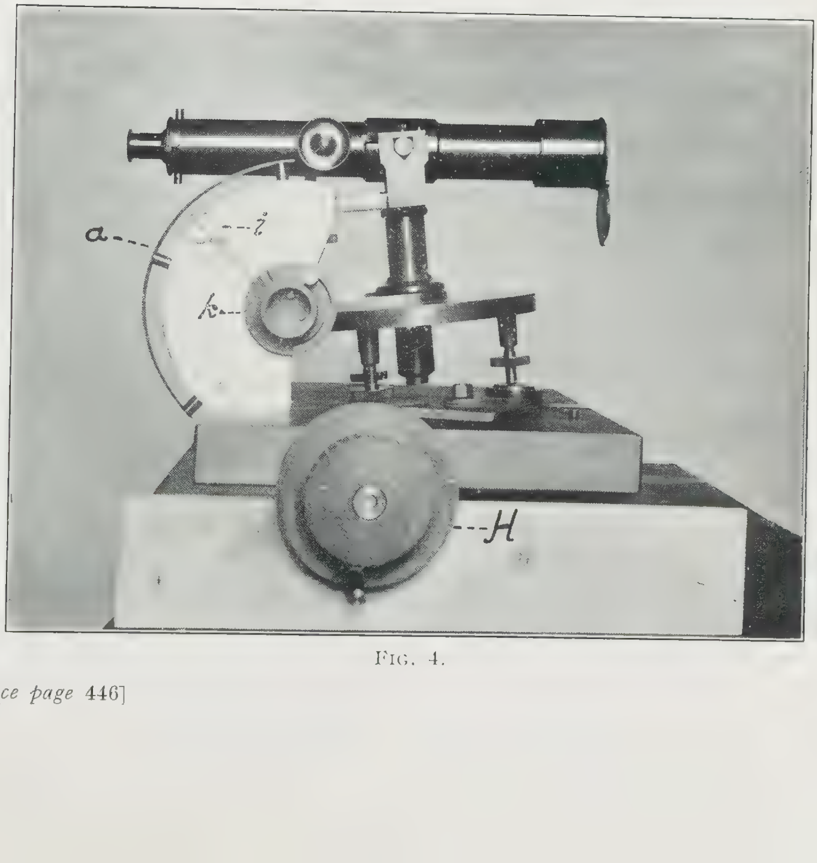

FIG. 4.

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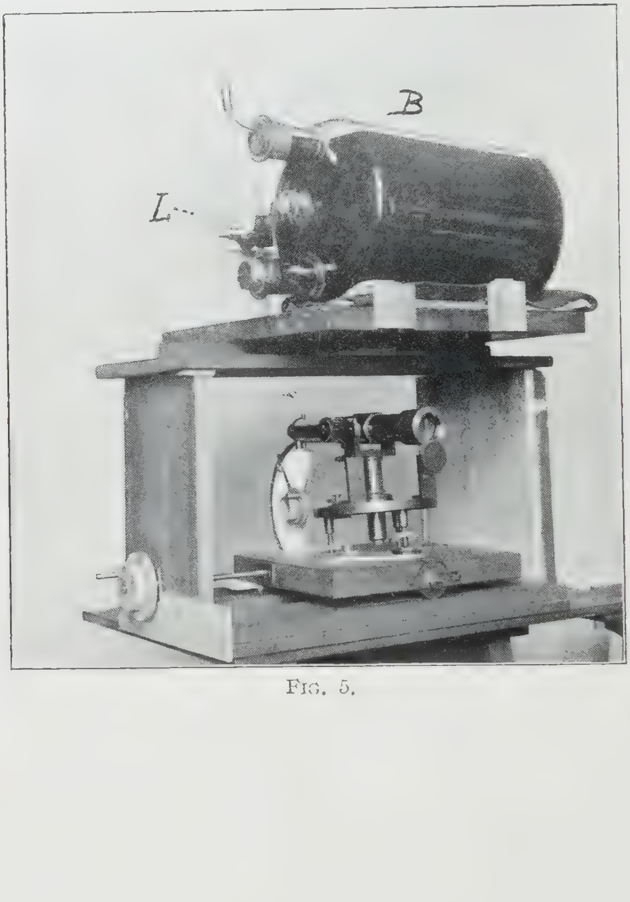

FIG. 5.

[*To face page* **447**

when the weight in one pan was changed by 4/50 mg. ; whence, $S=375$ per 0·1 mg.—that is to say, a deflection of 0·1 mm. corresponds to $2{\cdot}7\times10^{-7}$ grm. It has already been shown (*vide supra*), that the positional value of a rider was in the one case ascertainable to 5×10^{-6} and in the other to 5×10^{-7} grm. Hence, the accuracy with which the resting-point of the balance could be determined was now in excess of that attainable when setting a rider and amply sufficient for our purpose.

It will be understood that the actual process of weighing is not quite so simple as that outlined above. In describing the method used for measuring the position of a rider it was tacitly assumed that the scale engraving upon the beam was free from error ; and as this was not so, it was necessary to calibrate it. The calibration was carried out in the following way.

First the index i, Fig. 3, was set near the centre of its scale and its position a noted. Next the platform P was moved along by means of the screw s until the vertical cross-thread of the telescope coincided with the zero line on the beam. The index was then turned so as to transfer the cross-thread from the zero line to the next, and its new position β read. The first division of the beam was thus measured in terms of the scale a, Fig. 4, its indicated value being $\beta-a$ mm. The first division having been calibrated, the index was returned to its original position a and the telescope screwed along a second time, and on this occasion until it sighted the line marking division 1 ; then, on using the index as at first, the relative length of division 2 was determined. Proceeding thus, the whole scale was calibrated, and from the data obtained a table was prepared showing the weight values of the two riders for each of the 50 scale divisions upon the beam. The weight values for fractions of a scale division were found by interpolation. The plan adopted for guarding and lighting the beam must now be described.

Apparently the utmost accuracy in weighing can be attained only when the beam is enclosed and guarded against radiant energy.* Under ordinary circumstances the balance is readily affected and variations in its resting-point occur continuously. The beam of my own balance is protected by a small chamber which completely envelops it, also the glass panels of the case have been displaced by others of aluminium. The balance-room has but one window, and that is darkened during the operations of weighing, and whilst the balance is being loaded a water-cooled lamp is used. The powerful lamp employed for illuminating the vertical scale viewed by the second telescope (*vide supra*), is placed near the ceiling and screened by sheets of aluminium. Its light is thrown upon the scale by a system of lenses and a mirror.

When the resting-point has been determined and the beam arrested, an aluminium shutter covering the front is dropped and the tubular lamp L, Fig. 5, lit. The bottle B, filled with weak potassium chromate solution, constitutes a cylindrical lens ; and this not only forms a bright band of light along the entire length of the uncovered beam, but also absorbs heat rays emitted by L. The potassium chromate renders the light largely monochromatic, and so the scale upon the beam when viewed through the telescope appears remarkably sharp. A final precaution which contributed to success in the determination of small masses may now be dealt with.

In some balances the pan arrestors have their tops covered with velvet, the use of which may be detrimental in two ways. First, I find that the applied velvet usually exudes a substance which in time forms a film upon the bottom of the pan. It is improbable that such films are either equal for the two pans or permanent; hence, in the case of such a high-grade balance as that under discussion, variations in the resting-point must almost inevitably ensue. The correctness of this view may be verified by those possessing first-class sets of gilt or platinized weights. The weights when lifted from their velvet-lined cells, are usually somewhat dull, especially when they have not been used for some considerable time. The removal of the dullness by silk results in an appreciable decrease in value. That the observed loss is not due to the removal of a part of the weight itself may be demonstrated by repeating the experiment with a number of weights. Usually they are constant after the first rubbing.

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* Phil Trans. A, Vol. 210, p. 405.

Secondly, the pile of the velvet gradually flattens, and in consequence of this the arrestors and their pans tend to adhere. As the adherence is rarely the same in each case, a defect is manifested when the beam is brought into use, by the non-release of one of the pans. When the pan is that containing the object, the fractional weights placed in the other may for a time exceed those actually required for weighing. The errors and inconveniences arising from the above-named sources were, in the present instance, avoided in the following way.

First, the velvet coverings were removed, the heads of the arrestors turned flat and three small holes drilled through each. These holes were just within the rim and separated from each other by an angular distance of 120°. Finally, a short gold wire, the upper end of which terminated in a sphere* was placed in each hole and its lower portion bent against the under surface of the arrestor and thus secured. Armed with their triple contacts of gold, the arrestors have proved highly efficient.

Contacts of gold were chosen for the simple reason that the pans were gilded, hence the loss and gain of the engaging points and surfaces mutually and automatically compensate each other. Had the pans been platinized, the arresting spheres and their wires would have been of platinum.

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* The spheres were formed by fusing one end of each wire, which was 0·5 mm. thick, in the flame of a blowpipe.

XXXIX.—ELECTRICAL SEPARATION BETWEEN IDENTICAL SOLID SURFACES.

By P. E. SHAW, *M.A.*, *D.Sc.*, *F.Inst.P.*, University College, Nottingham.

Received February 20, 1927.

ABSTRACT.

(1) When one insulating solid is rubbed along and perpendicular to an identical one they acquire charges, $-^{ve}$ and $+^{ve}$, respectively.

(2) Continued rubbing so affects the surfaces of " rubber " and " rubbed " that their properties change, with reversal of sign to $+^{ve}$ and $-^{ve}$ respectively.

(3) The effect 2 is permanent, unless the surfaces be restored by heat treatment.

(4) Oblique impact of two identical solids generates on them unequal charges. The net charge is, in general, $-^{ve}$.

IN the old standard compilation of Tribo-electricity* mention is made of charges arising when apparently identical solids are rubbed on one another. One of these cases was observed by Faraday, using like feathers. But no systematic investigation has been accorded to these unexpected results in the long intervening period. It will be shown below that, when suitable care is taken, identical solids do charge one another by friction or impact in a *regular* way, and that at least for the many insulating bodies tried there is the same law of electrical separation for all. But if care be not taken the results will be found to be fortuitous.

The materials used are ebonite, celluloid, caoutchouc, sealing wax, shellac, amberite, sulphur, charcoal, paraffin wax, glass, vitreous silica, mica.

The most convenient form in the case of ebonite, celluloid, etc., is a rod, say, 10 cm. long and 1 cm. square section. Mica in thin sheet is wrapped round a glass tube and such material as shellac is melted on a glass rod.

RUBBING AT ORDINARY TEMPERATURE.

Ebonite.—In order to prepare the surfaces so that they may be identical they are thoroughly, but lightly, scraped with a keen razor edge and are then boiled in water till they are soft enough to bend easily. After drying and cooling the following effects are observed :—

(1) Placing the rods across one another, one (A) is rubbed down the other (B). We then find A is charged $-^{ve}$, B $+^{ve}$. Discharge the rods by the side of, *not in*, a flame. Rub B down A. We find B $-^{ve}$, A $+^{ve}$. This action occurs in all places, on both sides. Thus the surfaces are now identical in behaviour. The " rubber " in all cases being $-^{ve}$, the rubbed $+^{ve}$.

When the surfaces behave alike in this way, we call them " standard."

There is a real distinction between " rubber " and " rubbed," since a much smaller area of the former than of the latter takes part in the rub ; and consequently, of the two, the rubber attains the higher temperature and is softer and more likely to yield and be strained under the great tangential forces applied in friction.

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* " Reibungs electricitat," by Riess, publ. 1855.

(2) Continued rubbing of the standard rods brings about a change of effect, the rubber gradually loses its $-^{ve}$, and the rubbed its $+^{ve}$; in time they become neutral, and finally the signs are reversed with rubber $+^{ve}$, rubbed $-^{ve}$.

When in the neutral state, either rod may become $-^{ve}$, the other being $+^{ve}$ according to the places rubbing, since the permanent effect of rubbing will not be uniformly distributed. A light rub may give a $-^{ve}$ charge, a heavy one a $+^{ve}$, to the rubber. A curious effect is sometimes seen in the neutral state; a direct rub giving $+^{ve}$, a reverse rub $-^{ve}$, to the rubber.

(3) Prolonged rubbing results in the rubber always showing $+^{ve}$, the rubbed $-^{ve}$, and this condition is permanent, showing no change as time goes on. Let us call the new state of both rods *strained*, in contrast with the initial "standard" or *unstrained* state.

Without observing their electrical action it is easy to tell whether two surfaces are unstrained by their soft feel when rubbed together. After much rubbing the surfaces feel hard and "gritty" on rubbing.

(4) On scraping and boiling the rods, as in (1), they return to their pristine standard state. Thus we have a reversible cycle. A warning is necessary: the rods should not be rubbed after boiling until they are cold, since when hot the material is so soft that strain may be imposed very rapidly and steps (1) and (2) may run into one another.

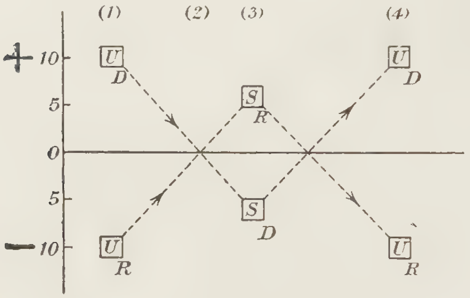

FIG. 1.

Sign and approximate amount of charge on surfaces unstrained (U) in (1), becoming strained (S) in (3), and by heat treatment reverting to unstrained in (4). R denotes rubber; D rubbed; (2) is the neutral state.

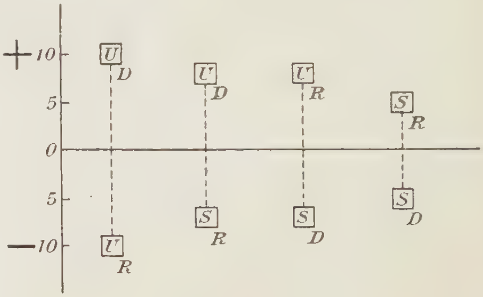

FIG. 2.

Sign and approximate charge of unstrained (U) or strained (S) surfaces, rubbed two at a time, depending on position as rubber (R) or rubbed (D).

The effects in the above experiments are shown graphically in Fig. 1, where the headings refer to the above four experiments.

The simple apparatus used to measure the charges has been described already.* A Hankel electroscope whose gold leaf is observed by a microscope has its parallel plates joined to a battery which maintains them at +50 volts and −50 volts respectively. The leaf is connected to an inductor which has the form of a brass tube about 8 cm. long and 8 cm. diameter. Into this inductor the charge to be measured is thrust. Since the charges are considerable it is best to raise the leaf clear of the parallel plates. Roughly speaking, one E.S.U. charge causes a divergence of 10 scale divs. in the microscope. In order further to indicate the strength of charges obtained in these experiments, it may be stated that when two standard ebonite rods are rubbed they give rise to charges one-tenth to one-twentieth of those obtained by rubbing an ebonite rod on warm flannel.

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* Proc. Roy. Soc., A., 111 (1926).

(5) A further experiment which contributes to the elucidation of these effects is as follows : Two surfaces are well rubbed together till they are strained, as shown in experiment (3). Two other surfaces are left unstrained. Rubbing them together in pairs we have U/U, S/U, U/S and S/S (*see* Fig. 2). The first and last of these four cases we have in experiments (1) and (3). The other two cases are new. If the figure be examined we find we can interpret all cases by the following rules :—

(*a*) The unstrained surface has a $+^{ve}$, and the strained a $-^{ve}$ tendency.

(*b*) The rubbed surface dominates the situation and decides the sign of the charges.

Having observed the behaviour of ebonite it may be stated at once that the other materials mentioned behave in the same way. All, except glass and vitreous silica (whose surfaces are relatively hard, and which show no charges) obey the rule that " rubber " is $+^{ve}$ when unstrained, $-^{ve}$ when strained. All of them on rubbing acquire strain with reversal of charge, which strain is final, but can be removed by heat treatment.

IMPACT EXPERIMENTS.

Dissimilar materials when struck together in normal impact develop opposite charges.* But, on trial, it is found that identical bodies also charge one another. A glancing blow, containing tangential as well as normal stresses, is best for the purpose. The result of a violent blow between identical specimens of our insulating materials is to give a net $-^{ve}$ charge almost invariably, whether the surfaces be standard or strained. To quote a few examples found in the case of ebonite, the charges on the two rods in scale units were $-13/+7$, $-27/+12$, $0/-14$, $-7/-4$. Prolonged blows in general increase the net $-^{ve}$ charge. In the case of caoutchouc, celluloid, shellac and sealing wax the surfaces if very strained show sometimes net $+^{ve}$, but the general rule for these and all the other materials is that net $-^{ve}$ arises. To quote one of the exceptions : Two standard celluloid surfaces on impact give $-20/+16$. On repeating the blows both $-^{ve}$ and positive are reduced, and finally when both surfaces are strained the charges formed are $+11/-5$, i.e., there is net $+^{ve}$.

DISCUSSION OF RESULTS.

From these experiments we learn that strain plays an important part in Tribo-electric effects, and it is clearly impossible to solve the general problems of the genesis of charges in Tribo-electricity unless this new factor is given due weight.

We reduce by one the variables in the equation by using, as in these experiments, only one kind of material.

Analogous with the behavior of insulators in acquiring strain when pressed is that of metals whose surfaces are unstrained (crystalline) after fusion and become strained (vitreous) by pressure.† We have a hint of the difference in physical characteristics in these two states of a metal, since a crystalline and a vitreous specimen show the Peltier effect at their interface.*

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* *See* Richards, Phy. Rev., p. 290 (1920).

† *See* Sir G. Beilby's " Aggregation and Flow of Solids."

The net total $-^{ve}$ charge found in impact experiments in Section (4) is most readily interpreted by supposing that $+^{ve}$ ions escape to the air when the impacting solids separate.

A suggestion may be made. Electrical snowstorms and sandstorms have ever been a mystery. But since, as in these experiments, like particles in impact may attain one charge, and the air an opposite charge, the repeated and violent blows between the particles of snow or sand may gradually accumulate a large charge on the particles and an opposite one in the air. We should then have a state of affairs such as arises from a different cause in an ordinary thunderstorm when the water drops are $+^{ve}$ and the $-^{ve}$ ions are dissipated in the air.

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* *See* Beilby, loc. cit.

XL.—DIFFRACTION OF LIGHT BY A TRANSPARENT LAMINA.

By Prof. C. V. RAMAN, *F.R.S.*, and I. RAMAKRISHNA RAO, *M.A.*

ABSTRACT.

The present Paper embodies an attempt to consider the problem of diffraction of light by a *very thin* plate of transparent material, bounded by a straight edge, with greater exactness than is attained in the usual elementary treatment on the Fresnel-Huygen principle. The method adopted, though not completely rigorous, bases itself on the electromagnetic theory of light, and seeks to express the disturbance in the field in the form of functions which are solutions of the equations of wave-propagation. The formulæ obtained indicate that the light diffracted by the edge should exhibit colour and polarization effects varying in a remarkable manner with the thickness of the plate and the direction of observation. Effects having the general character of those indicated by the theory have actually been observed in experiment. The theory, however, requires modification in the case of thicker laminæ, where further complications arise which are not here taken account of.

I. INTRODUCTION.

THE problem of diffraction by a plane transparent lamina arises in considering the theory of such phenomena as the colours exhibited by the " striæ " or laminar boundaries in mica,* and the colours of mixed plates.† It has been observed that the edges of thin laminæ diffract light through large angles, and that the light thus diffracted exhibits colour and polarization effects which are in some respects analogous to those discovered by Gouy‡ with metallic edges. The elementary treatment of laminar diffraction usually given is thus inadequate. In the present Paper an attempt is made to place the theory of diffraction by laminar boundaries on a more satisfactory basis. The case of a thick lamina is too complicated to offer hope of an exact solution. In the case of a thin lamina, however, certain simplifications are possible, as we shall see presently, which enable the problem to be dealt with successfully.

II. THEORY.

We shall confine ourselves to the case in which the light is incident on the lamina in a plane perpendicular to its edge. The region round the lamina can then be divided into three parts: The first consists of the region in which the light transmitted through the lamina alone appears. The second is the region in which only the incident waves appear. The third is the region in which the incident and reflected waves are superposed.

The middle surface of the lamina may be taken as the plane $\varphi=0$, and its edge as the Z-axis in a system of cylindrical co-ordinates. We may represent the incident wave by the expression

$$e^{i\cdot 2\pi t/T}\, e^{i\kappa\rho\cos(\varphi-\varphi_0)} \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

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* C. V. Raman and P. N. Ghosh, Nature, Vol. 102, p. 205 (1918).

† C. V. Raman and B. N. Banerji, Phil. Mag., Vol. 41, p. 338 (1921).

‡ G. Gouy, Annales de Chimie et de Physique, Vol. 8, p. 145 (1886).

φ_0 being the angle between the plane of the lamina and the incident rays. The train of waves reflected from the lamina may be represented by the expression

$$-e^{i\,.\,2\pi t/\mathrm{T}}\,(A_s+iB_s)\,e^{i\kappa\rho\cos(\varphi+\varphi_0)} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

or by

$$e^{i\,.\,2\pi t/\mathrm{T}}\,(A_p+iB_p)\,e^{i\kappa\rho\cos(\varphi+\varphi_0)} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

and the train of waves transmitted through the lamina by the expression

$$e^{i\,.\,2\pi t/\mathrm{T}}\,(C_s+iD_s)\,e^{i\kappa\rho\cos(\varphi-\varphi_0)} . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (4)$$

or by

$$e^{i\,.\,2\pi t/\mathrm{T}}\,(C_p+iD_p)\,e^{i\kappa\rho\cos(\varphi+\varphi_0)} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (5)$$

The expressions (2) and (4) refer to the case (which we shall refer to as the $\|^l$ case), in which the planes of incidence and polarization are coincident. The expressions (3) and (5) refer to the case (which we shall refer to as the $\perp^r$ case) in which they are mutually perpendicular. The multiplying factors (A_s-iB_s), etc., are those given by the well-known theory of the colours of thin plates,* and may be deduced directly from the electromagnetic theory so as to satisfy the boundary conditions on either face of the lamina.

Now the disturbances represented by expressions (1) to (5) do not extend throughout the whole field, but are confined to the particular regions of the field already indicated. To find the solution of the diffraction problem, we seek a function which satisfies the equations of wave-propagation, and which, while being valid throughout the whole field outside the substance of the lamina, represents a disturbance approaching asymptotically to the values given by those expressions at a sufficient distance from the origin in the respective parts of the field to which they refer.

Such an expression is

$$u=F(\rho,\ \varphi,\ \varphi_0)-(A_s+iB_s)F(\rho,\ \varphi,\ -\varphi_0)+(C_s+iD_s)F(\rho,\ \varphi,\ \varphi_0-2\pi) \quad . \; . \quad (6)$$

or

$$u=F(\rho,\ \varphi,\ \varphi_0)+(A_p-iB_p)F(\rho,\ \varphi-\varphi_0)+(C_p-iD_p)F(\rho,\ \varphi,\ \varphi_0-2\pi) \quad . \; . \quad (7)$$

in which $F(\rho,\ \varphi,\ \varphi_0)$ is the well-known solution of the wave equation due to Sommerfeld.

$$F(\rho,\ \varphi,\ \varphi_0)=e^{i\,.\,2\pi t/\mathrm{T}}\left(\frac{i}{\pi}\right)^{\frac{1}{2}} e^{i\kappa\rho\cos(\varphi\quad\varphi_0)}\int_{-\infty} e^{-i\lambda^2}\,d\lambda \quad . \; . \; . \; . \; . \; . \; . \quad (8)$$

where

$$T=\sqrt{2k\rho}\,\cos\tfrac{1}{2}(\varphi-\varphi_0) \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (9)$$

$F(\rho,\ \varphi,\ -\varphi_0)$ and $F(\rho,\ \varphi,\ \varphi_0-2\pi)$ are obtained by writing $-\varphi_0$ and $(\varphi_0-2\pi)$ respectively for φ_0 in (8) and (9).

In the $\|^l$ case u represents the electric force parallel to the edge of the screen and in the $\perp^r$ case it represents the magnetic force in the same direction. It can readily be verified that the asymptotic values of (6) and (7) are those given by (1),

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* Drude's Theory of Optics, English Translation, p. 302.

(2), (3), (4) and (5), in the parts of the field to which they refer. When (9) is positive, the asymptotic expansion of (8) is

$$F(\rho,\ \varphi,\ \varphi_0)\sim e^{i\,.\,2\pi t/\mathrm{T}}\left[e^{i\kappa\rho\cos(\varphi-\varphi_0)}+\frac{i^{3/2}e^{-i\kappa\rho}}{4\pi\sqrt{\rho/\lambda}\cos\frac{1}{2}(\varphi-\varphi_0)}\right]\quad .\ .\ .\ .\ (10)$$

while, if (9) be negative, there is a similar expansion in which the first term is left out The light diffracted by the edge may accordingly be written thus

$$E_z=e^{i\,.\,2\pi t/\mathrm{T}}\,.\,\frac{i^{3/2}e^{-i\kappa\rho}}{4\pi\sqrt{\rho/\lambda}}\left[\frac{1-(C_s+iD_s)}{\cos\frac{1}{2}(\varphi-\varphi_0)}-\frac{A_s+iB_s}{\cos\frac{1}{2}(\varphi+\varphi_0)}\right]\quad .\ .\ .\ .\ .\ (11)$$

$$H_z=e^{i\,.\,2\pi t/\mathrm{T}}\,.\,\frac{i^{3/2}e^{-i\kappa\rho}}{4\pi\sqrt{\rho/\lambda}}\left[\frac{1-(C_p+iD_p)}{\cos\frac{1}{2}(\varphi-\varphi_0)}+\frac{A_p+iB_p}{\cos\frac{1}{2}(\varphi+\varphi_0)}\right]\quad .\ .\ .\ .\ .\ (12)$$

We may write the expression within the square brackets in (11) and (12) respectively in the form (F_s+iG_s) and (F_p+iG_p). $(F_s^2+G_s^2)$ and $(F_p^2+G_p^2)$ are measures of the intensity of the components in the radiation diffracted from the edge, and their ratio indicates its state of polarisation when the incident light is unpolarised. $\delta_s=G_s/F_s$ and $\delta_p=G_p/F_p$ give the phases of the components, and $(\delta_p-\delta_s)/\lambda$ is a measure of the ellipticity of the diffracted radiation when the incident light is polarized in any arbitrary azimuth.

III. NORMAL INCIDENCE: VERY THIN LAMINA.

In the case of normal incidence, we have $\varphi_0=\pi/2$, and further

$$\mathrm{A}_s+iB_s=A_p+iB_p=\frac{i(\mu^2-1)\sin p}{i(\mu^2+1)\sin p+2\mu\cos p}\quad .\ .\ .\ .\ .\ (13)$$

$$C_s+iD_s=C_p+iD_p=\frac{2\mu(\cos q+i\sin q)}{i(\mu^2+1)\sin p+2\mu\cos p}\quad .\ .\ .\ .\ .\ (14)$$

where $p=2\pi\mu d/\lambda$ and $q=2\pi d/\lambda$, d being the thickness of the lamina and μ its refractive index. We have only to substitute (13) and (14) in equations (11) and (12) and evaluate them numerically to find the intensity and state of polarization of the diffracted light in any direction.

Consider first a lamina so thin that we may put $\sin p=p$, $\sin q=q$, $\cos p=\cos q=1$. Since $p=\mu q$, we find readily on making these substitutions, that

$$1-(C_s+iD_s)=1-(C_p+iD_p)=A_s+iB_s=A_p+iB_p$$

and that

$$F_s+iG_s=\frac{\pi(\mu^2-1)d}{\lambda}\left[\frac{1}{\cos\dfrac{\varphi-\varphi_0}{2}}-\frac{1}{\cos\dfrac{\varphi+\varphi_0}{2}}\right]\quad .\ .\ .\ .\ .\ (15)$$

$$F_p+iG_p=\frac{\pi(\mu^2-1)d}{\lambda}\left[\frac{1}{\cos\dfrac{\varphi-\varphi_0}{2}}+\frac{1}{\cos\dfrac{\varphi+\varphi_0}{2}}\right]\quad .\ .\ .\ .\ .\ (16)$$

From (15) and (16), it follows at once that along the surface of the screen ($\varphi=0$ and $\varphi=2\pi$), the $\|^l$ component of the diffracted light would be zero, and the $\perp^r$ component would be finite, thus giving complete polarization. In the opposite direction

($\varphi=\pi$), however, the $\|^l$ component of the diffracted light would be finite, and the $\perp^r$ component would be zero, thus again giving complete polarization but in a perpendicular plane. The intensity of the diffracted light would, for such thin laminæ, be proportional to the square of the thickness.

IV. THICKER LAMINÆ: COLOUR AND ELLIPTIC POLARIZATION.

If we assume that formulæ (11) and (12) remain valid for greater thicknesses of the lamina, at least as an approximation, it is evident from these expressions taken together with (13) and (14) that the intensity and state of polarization of the diffracted light would be functions of the wavelength, the thickness of the lamina, and the angle of diffraction. Hence, in white light, the diffracted radiation from the edge would exhibit colour.

If we assume that the incident light is unpolarized, the diffracted light from the edge would be partially polarized to an extent depending essentially on the contribution proportional to (A_s+iB_s) or (A_p+iB_p) which arises from the reflected wave and appears with a negative sign in (11) and with a positive sign in (12). It follows that the degree of polarization should vary with sin p in a periodic manner, being zero when the thickness of the lamina is such that the reflected light vanishes and maximum for intermediate thicknesses. The intensity of the diffracted light, however, depends chiefly on the resultant of the contributions from the incident and transmitted waves which are proportional to $(1-C_s-iD_s)$ or $(1-C_p-iD_p)$. It is easily shown that this part depends on sin $(p-q)$ and that its intensity is a maximum when the relative retardation on the two sides of the boundary is half a wavelength, and a minimum when the relative retardation is a complete wavelength, and so on. Two sets of periodic variations in intensity thus occur giving rise to corresponding colour effects in the diffracted light. One set of variations affects both components of the vibration in the same way, while the other set affects the two components in opposite senses. Hence, the colour of the diffracted light would, to some extent, depend on the azimuth of polarization, and the two images of the diffracting edge seen through a double-image prism may in favourable cases actually exhibit complementary colours.

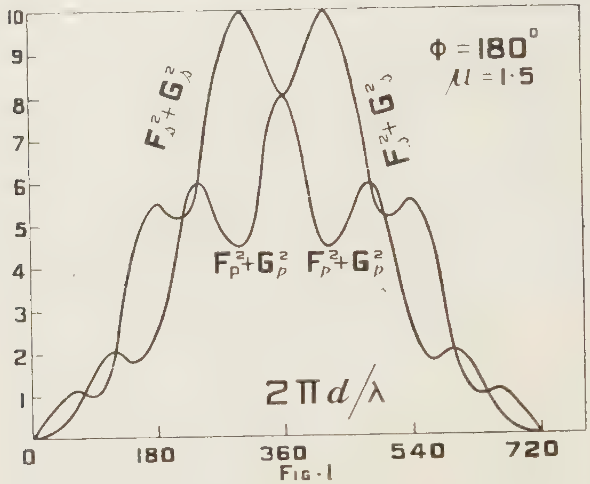


FIG. 1

INTENSITIES OF COMPONENTS OF DIFFRACTED LIGHT AS FUNCTIONS OF THICKNESS.

Fig. 1 represents the values of $F_s^2+G_s^2$ and $F_p^2+G_p^2$ corresponding to an angle of diffraction of 90° ($\varphi=180°$) for different thicknesses of the lamina, the refractive index being assumed to be 1·5. The periodic variations of the $\|^l$ and $\perp^r$ components of the intensity of the diffracted light are clearly seen. The polarization, which is given by the ratio of the two components, is almost complete for small thicknesses of the lamina ; it is zero for thicknesses given by $2\pi d/\lambda = 78°$, 120°, 218°, 240° and 360°. For intermediate thicknesses, the polarization fluctuates.

From (11), (12), (13) and (14) it is obvious that, when the incident light is plane-polarized in any azimuth, the diffracted light would in general be elliptically polarized. The phases of the $\perp^r$ and $\|^l$ components as calculated from the values of $\tan^{-1}(G_p/F_p)$ and $\tan^{-1}(G_s/F_s)$ respectively are shown in Fig. 2 for the same cases as those considered in Fig. 1. It is evident from the figure that, in certain cases, particularly for small thicknesses of the lamina, the phase differences are large and should easily be observed.

V. Supplementary Remarks.

The theory set out above is an approximation to the truth which is strictly applicable only to the thinnest laminæ. It succeeds in explaining the polarization effects which would otherwise be unintelligible. With laminæ of greater thickness, however, complications arise which are not here taken account of. In reality, we have not one edge, but two edges to deal with, namely, those relating to the front and rear surfaces of the lamina, at which the waves passing on either side of the boundary are diffracted and, diverging with a difference of path, interfere with each other.

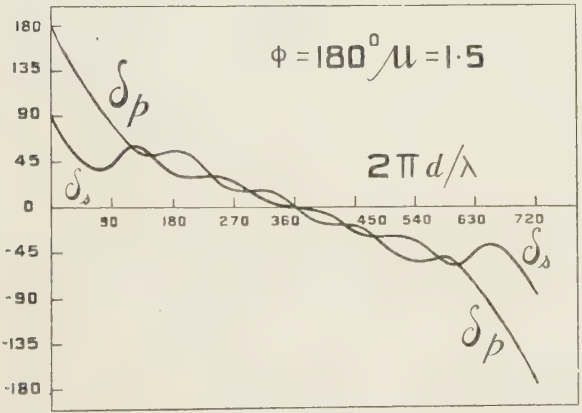


Fig. 2

Phases of Components of Diffracted Light as Functions of Thickness.

It is readily seen that the path-difference between the interfering rays from the two edges would alter continually with increasing deviation of the diffracted ray, but in different ways in the two portions of the field to the right and the left of the direction of the incident pencil. Since the conditions on the two sides of the boundary between the incident and transmitted waves are thus dissimilar, the diffraction effects observed should be asymmetrical in intensity with reference to this boundary. Experimentally this is actually observed to be the case. Further, owing to the interference of the diffracted waves from the front and rear edges occurring under varying difference of path in different directions, the colour and intensity of the diffracted light should vary periodically with increasing deviation of the diffracted ray. This again is actually observed in experiment. It is not unlikely that a modified treatment which takes account of the complications referred to here may be successfully worked out. To enter into them more fully, however, or to make detailed comparisons between theory and observation would lie beyond the scope of the present Paper.

XLI.—LECTURE ON THE ECLIPSE OF THE SUN, JUNE 29, 1927.

Delivered by E. H. Rayner, *M.A., Sc.D.*, on June 3, 1927.

Extracts from Lecture.

THE initial partial phase and totality take place before 6 a.m. G.M.T. In such circumstances the diurnal rotation causes England to have a small component opposite to the eastward motion of the moon's shadow. The final (fourth) contact will occur after 6 a.m. over England, and the partial phase at commencement will be some 3½ minutes shorter than that after totality. The times mentioned in this lecture are G.M.T. The centre of the shadow cone makes first contact with the earth at 5 H. 20·1 M. G.M.T., only 3 minutes before it reaches Cardigan Bay. At this point the diameter of the cone where it intersects the earth is about 13·7 miles, and the distance of intersection from the imaginary point is about 1,500 miles. In the two succeeding minutes, when the intersection is near Hartlepool, the diameter increases to about 16 miles, corresponding to about 1,700 miles from the point. Owing to the low altitude of the sun, the intersection of the shadow cone with the earth's surface is a long ellipse. The minor axis of the ellipse is only about half of the 30 mile width of the shadow track, since the major axis of the ellipse is inclined at about 23° to its direction of motion. The conditions at 5.25, which have been kindly provided by Dr. Comrie, are given in Fig. 1, in which the dimensions are in miles. One result of these circumstances is that over the northern two-thirds of the shadow track the approach of the shadow will appear to be from the E. of S., and not from the S.W. The direction at Richmond will be about 15° E. of S. The apparent velocity will be considerably less than the velocity of travel.

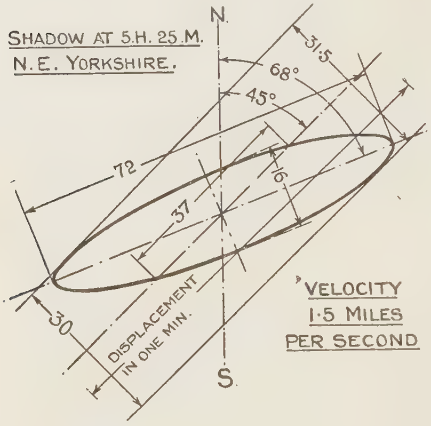


Fig. 1.

Particulars for Richmond, Yorks.

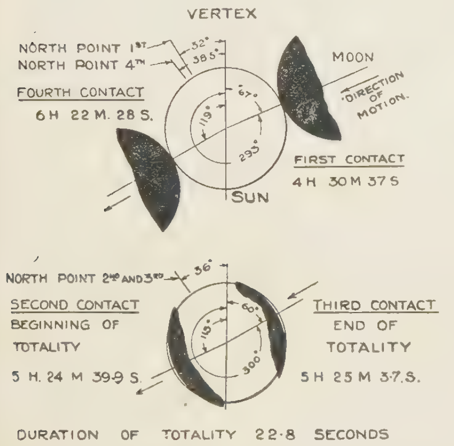
The progress of the eclipse has been computed for the Race Course at Richmond, Yorkshire. The information includes the times of the four contacts and their position angles. The moon will first be seen to encroach on the sun at 4 H. 30 M. 37 S. at an angle of 293° from the vertex, that is, from the highest point of the sun as seen at that time and place (Fig. 2). The angles are computed starting from North through East, to the left. The point is more conveniently found by considering it as 67° from the vertex counting towards the right.

The passage of the leading edge of the moon across the sun's disc takes about 54 minutes, the second contact, which is the commencement of totality, occurring at 5 H.

24 M. 39·9 S. Totality is computed to last 22·8 seconds ending with third contact at 5 H. 25 M. 3·7 S. The fourth contact, when the sun is finally clear of the moon is about 57·5 minutes later. The various times, position angles from the vertex and the direction of the North point of the sun are shown in the diagram.

Estimation of the Moment of Totality by Measurement of the Solar Crescent.

It is desirable to have an observational method of some accuracy for estimating the moment when totality is to commence a few seconds before it actually does so. When the moon has nearly covered the sun a diminishing crescent of the solar disc is visible. If the angular dimension or chord of this cusp has been computed for a number of instants before totality, it enables the desired time interval to be obtained by a direct measurement of the cusp. This measurement can be made by projecting the image of the sun, produced by a stand telescope, on to a white card, using the eye-piece as a magnifier in the usual manner. An image of the sun two or more inches in diameter can usually be obtained by this means. On the card pairs of parallel lines can be drawn, each pair being separated by a distance corresponding to the length of the chord of the cusp at a known interval before totality. The card is oriented so that the lines are parallel to the moon's apparent motion.



TIMES OF CONTACT AND POSITION ANGLES FOR LAT. 54° 24·6′ N. 1° 45·5′ W. BEING THE POSITION OF THE S.W. CORNER OF RICHMOND RACE COURSE.

Fig. 2.

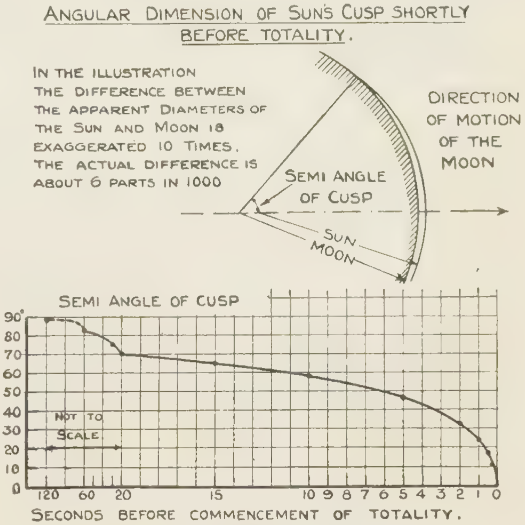


Fig. 3.

Fig. 3 shows the dimensions of the semiangle of the cusp in degrees, from which the corresponding chord can be computed. The chord will be D sin C, where D is the diameter of the image of the sun and C the semiangle of the cusp. In Fig. 4 the diameter of the sun is indicated by that of the semicircle, and the relative lengths of the chords from 20 to 0·5 seconds before (and after) totality are given by the corresponding numbers. The computation has been made on the assumption that the semi-diameter of the sun is 943·9 seconds, that the apparent semi-diameter of the moon is 950·1 seconds, and that the time of totality is 22 seconds. The relative motion assumed has been that of the centre of one disc moving along a diameter of the other. A rigid computation for the circumstances of Richmond, computed by Dr. Comrie, has confirmed these results very closely. The diagram may be used for places along the line of totality and for about five miles on each side with sufficient accuracy for the purpose intended.

CHROMOSPHERE.

The most striking part of the chromosphere may be expected to be the hydrogen prominences. The predominant visual light in the hydrogen spectrum is the red line at wavelength 6563. There are also other lines of shorter wavelength in the green and blue. These will tend to render less distinctive the red line, which is likely to be masked also by the general brightness of the corona. It may, therefore, be well worth while to try, for a second or two, even if not very successful, some method of enhancing the effect of this red hydrogen spectrum line.

A red glass of a common commercial quality cuts out practically all the blue and green of the spectrum and lets through only the orange and red. If the density of the colour is such as to absorb nine-tenths of ordinary daylight, the fraction of the line transmitted of the wavelength 6563 will be about one-half. There will be, therefore, a very considerable enhancement of the appearance of the hydrogen prominences, as seen in the light of this wavelength, compared with the general brightness of the corona. Two such glasses in series would cut down the red hydrogen line to a quarter of its intensity, while on the basis of average daylight it would only transmit 1 per cent.

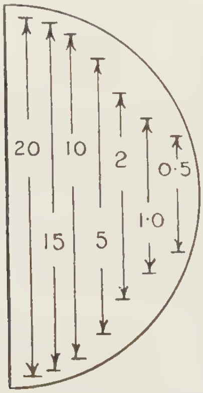


FIG. 4.

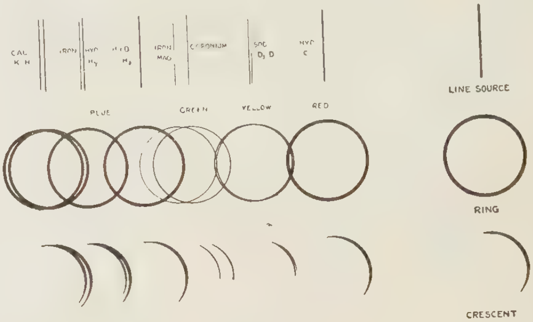


FIG. 5 (NEGATIVE).

A number of such glasses 3 in. by 2 in. in size are available, and it is proposed to distribute them to the Fellows of the Society and their friends on the journey to Richmond. The colour is similar to that of glass for photographic dark-room illumination, and to that used for the red light of railway signals.

A more analytical method of observing the chromosphere is by the use of a prism or grating to separate the light of different wavelengths.

The method is described in dealing with the " Flash " spectrum. The diagram Fig. 5 shows the appearance of light of the principal chromospheric lines as viewed through a straight slit, a circular slit and a crescent-shaped slit. It is not unlikely that the hydrogen lines, and possibly others, may be continuous all round the sun, or nearly so. The bright lines, green and red, due to the corona material, only visible during a total eclipse, may be expected to be visible as complete rings, not so bright as the chromosphere, and more diffuse because more extensive.

FLASH SPECTRUM.

Professor A. Fowler has suggested that, owing to the small difference between the apparent sizes of the sun and moon and to the probable brightness of the corona, there is a risk of observers not being aware that totality has commenced. The observation of the " flash " spectrum affords an accurate method of determining the limits of totality. At the base of the chromosphere, and for a distance of about 500 miles above the surface of the photosphere, there is a fairly sharply defined layer of metallic vapours as seen from the earth. These normally absorb some of the intense solar radiation of their own frequency passing through them, and give rise to the dark lines in the solar spectrum. At the moment of totality these gases in the region just clear of the apparent edge of the sun, not having its radiant surface behind them, do not give rise to an absorption spectrum; but, being at a sufficiently high temperature, they emit their own characteristic radiation, giving a spectrum of bright lines, the positions of which are the same as the corresponding lines of the absorption spectrum. This layer is comparatively thin, and the moon, traversing the sun's disc at a rate of 280 miles a second, soon covers it; so that the bright-line " flash " spectrum may only appear for a couple of seconds, though it may be visible longer in regions of activity. A plain or direct-vision prism is suggested for the observation of it and of the chromosphere, with or without any optical aid such as a field glass. For further information and suggestions as to what to look for, reference should be made to the Paper by Professor Fowler in the Journal of the British Astronomical Association, Vol. 37, No. 6, p. 205, price 3s., Eyre and Spottiswoode.

If accurate measurements are made of the time of appearance of the " flash " spectrum at the beginning and end of totality, referred preferably to the radio time signals, they may prove of distinct value. Any records should state whether the beginning or end of the " flash " is the moment recorded, and an estimate or measurement of its duration should be attempted.

SHADOW BANDS.

These appear to be a common feature of total eclipses. They have the appearance of alternate light and dark bands which are visible on the ground and other objects just before totality and after it. They are described as being in movement, but the movement does not appear to be too rapid to distinguish them. Their separation seems to be a matter of inches rather than feet. It is not known whether they have been photographed. It seems likely that they are a diffraction phenomenon caused by the last part of the solar disc being hidden by the moon, modified by atmospheric unsteadiness. The roughness of the moon's edge may be an important factor in their production. Preparations have been made to photograph them at one previous eclipse at least, which failed owing to clouds. A camera was focussed on white surfaces, one vertical facing the sun, and the other in front of it on the ground. An instantaneous photograph was to be attempted. A similar arrangement using a cinematograph camera or cinekodak would give an opportunity for determining not only the direction in space of these bands, but also their direction of progress. It is believed that any information of this character could not fail to lead to new knowledge. The ratio of the brightness of the light from the dark and bright parts is not known, nor the approximate absolute brightness, but it is hoped that a photograph would give a recognisable record. A lens of large aperture would be necessary, as the general intensity of the light w ll be very low.

General Notes.

No one can fail to be impressed and have but an imperfect appreciation of the lapse of time during an eclipse. It is not unlikely that the diminution of daylight up to about a minute before totality may appear to many to be unexpectedly slight. The eye is so used to intensities varying many fold in a few minutes on ordinary days, and is naturally so adaptable, that it is possible that only the last few seconds may be conspicuous in this respect. The general tone of the illumination is likely to be very striking for some time before totality.

If attempts are made to do any timekeeping during totality for photographic or other observational purposes, or even for the purpose of making the most of the opportunities for visual observation, it is well to count seconds backwards. Counting in this manner avoids attempting to do mental arithmetic in order to find out how many seconds yet remain. A metronome should be used or some other audible signal, so as to avoid the use of the eye for this purpose. It is well to aim at underestimating the time of totality, and for a duration of 22 or 23 seconds it would be well to start counting from 20.

For the protection of the eyes while directly observing the sun some dark glass or similar material must be used. A transmission of about a hundred thousandth of the incident light is sufficient. A photographic film given an exposure to the sky in a camera of about the normal time and then developed to give a good dense deposit will transmit too much light if used singly. Two, three or four thicknesses can be superposed, a suitable number being found by trial. Process plates will give a denser deposit, and the use of glass will avoid the diffuseness due to the use of several thicknesses of celluloid. For information concerning photography of the corona, etc., reference should be made to page 208 of the Journal of the B.A.A., previously mentioned.

Radio Time Signals.

Provision for the reception of radio time signals will be desirable, and it would be well for anyone providing such equipment to have a megaphone, in places where a considerable number of observers are expected.

It is specially desired that only the stations advertised as providing a public service should be tuned to, as delicate radio experiments are to be made on a number of other wavelengths. These may be seriously interfered with, if there is any attempt to tune to their wavelength. There will be nothing to listen to, as there will be no modulation. The radio experiments are extending over several days, during the early morning. The programme of the B.B.C. as regards time signals is as follows :—

Transmission of Greenwich Signals from Daventry on 1,600 Metres on June 29, Summer Time.

(1) Six dot seconds at 6.0, 6.15, 6.20, and 6.30 a.m.

(2) Single seconds continuously from 6.22 to 6.26 a.m., missing each 29th and 59th second with an announcer calling the 5th, 10th, 15th, etc.

DEMONSTRATION OF THE PRODUCTION OF SPLASHES BY ELECTRIC DISCHARGE.

By G. L. Addenbrooke.

THE experiments shown were an extension of those shown by Mr. Addenbrooke at the Physical Society's Exhibitions in 1926 and 1927, and have been described by him in The Philosophical Magazine, May, 1927.

A point electrode is mounted about 1 inch above a liquid dielectric (oil) and charged from an induction coil giving a 1-inch spark. For the purposes of optical projection the liquid is contained in a dish with metal rim and glass bottom. When the point is positively electrified, elongated radial splashes in the form of indentations spread out over the liquid and then sink into it. Similar results are obtained with a negatively charged electrode mounted nearer to the surface, the splashes covering a smaller area and being more definitely radial in this case. When a sphere of 1·5 cm. radius is substituted for the point, a circular hollow with a raised edge, from which the rays shoot out, is formed under the sphere.

DEMONSTRATION OF THE SCHÖNHERR-HESSBURGH NITROGEN FIXATION ARC.

By Capt. G. I. FINCH, *M.B.E.*

THE combustion of free nitrogen to nitric oxide is an endothermic process, and therefore involves absorption of energy. In the arc nitrogen fixation processes this energy is furnished by means of an electric discharge. The suitability of an arc for this purpose depends in the main upon the extent to which the following requirements are fulfilled: (i) The arc must burn satisfactorily on an alternating-current supply of the usual frequency, (ii) without giving rise to excessive load fluctuations, and (iii) it should be possible to maintain a high rate of flow of air through the arc.

In the Birkeland-Eyde arc these conditions are sufficiently realised by magnetic, assisted to some extent by blast, quenching; and in the Pauling Brothers' arc by blast quenching alone. Both arcs are burnt between water-cooled copper tube electrodes. Thus immediately on striking at the beginning of each half-cycle (suitable inductance being included in the circuit to cause the voltage to lead to the necessary extent) the arc is distended—i.e., the arc gap virtually widened—and the heavy load fluctuations, which would otherwise occur owing to the characteristic of the discharge being negative, are suppressed. Further, since the origins of such quenched arcs are never stationary, but always receding rapidly from the gap, the cathode remains cool and the cathodic fall of potential is consequently of the order of 430 to 450 volts. Thus the Birkeland-Eyde and Pauling arcs are both cold cathode—i.e., true high-tension arcs.

The Schönherr-Hessberger arc differs fundamentally from either of those previously mentioned. This arc is not quenched; when once it has been struck and fully extended to its normal working length the latter remains constant. Further, the arc origins are stationary, and, although the iron rods upon which they are seated are water-cooled, such cooling does not suffice to prevent the formation of highly heated oxide layers at which the cathodic potential fall is of the order of only about 10 volts. Thus the Schönherr is a hot cathode—i.e., low-tension arc.*

The Schönherr-Hessberger furnace consists essentially of a long (30 ft., or even more) vertical iron tube, at either end of which are situated axially the two iron rod electrodes, of which the upper one and the tube are earthed. Air is blown through jets let in tangentially at the bottom of the furnace. This arrangement results in a helical movement being imparted to the air flowing up the tube, and thus preserves a practically stationary vertical column of air between the electrodes. On first striking an arc is formed between the bottom electrode and an adjacent point on the iron tube ; but the arc origin on the latter is immediately carried up the tube by the swirling air current, until it finally lodges on the upper central electrode. Owing to the comparatively undisturbed state of the central air column now traversed by the discharge, the temperature and highly ionised condition of the gases therein persist sufficiently to enable the arc to re-strike almost immediately on reversal of the current at the close of each half-cycle.

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* The terms "low" and "high tension" as applied to the arc are apt to be somewhat misleading. It would certainly give rise to less confusion if the classification were based on the temperature of the cathode alone. For whilst the *minimum* striking potential of a hot cathode arc between, for example, carbon electrodes in air is only about 36 volts, and as much as from 450 to 470 volts when the cathode is cold, conditions can easily be realised in which the total potential drop across a hot cathode, "low tension" arc exceeds that across a cold cathode, "high tension" arc. A "high tension" arc with stationary origins, even on water-cooled but oxidisable metal electrodes, invariably breaks down into one of the hot cathode variety, unless, indeed, the current passed by the discharge be exceedingly small.

The Schönherr arc can be effectively demonstrated on a small scale in the following manner : A 1½ inch bore, 18 inches long, transparent quartz tube is clamped vertically and provided with a 3 inches long electrode of ¼ inch iron rod secured centrally by means of a rubber bung inserted into the lower end of the tube. Two glass tubes are passed through this bung, and their ends inside the quartz tube bent over at right angles, thus forming tangential blast jets. An upper ¼ inch thick iron rod electrode can be moved up or down along the axis of the tube, being guided in a glass tube held centrally in a bung in the upper end of the quartz tube. The secondary of a 1 kilowatt transformer working off a supply of the ordinary frequency and with a secondary output voltage of between 3,000 and 20,000 volts, is connected to the electrodes. Should the transformer secondary be centre-earthed, it will be necessary to insulate the upper electrode ; otherwise it may be earthed in the interests of both convenience and safety. The movable electrode is now lowered towards the bottom one until the arc strikes, whereupon it is rapidly withdrawn to practically the full extent of the quartz tube. The arc thus formed is of strikingly beautiful appearance, brilliant golden white in colour and about ¾ inch in diameter. It moves sinuously and slowly about inside, but without ever actually touching the walls of the tube. On turning on the blast the discharge shrinks somewhat in diameter, and is steadied up until practically no motion can be detected in it. The gases leaving the upper end of the tube contain about 2 per cent. of nitric oxides and are strongly coloured.

DEMONSTRATION WITH MAGNETRON.

By D. Owen, *B.A.*, *D.Sc.*

THE magnetron is a diode valve with cylindrical anode of non-magnetic material, along the axis of which lies the filament. A uniform magnetic field can be supplied parallel to the axis. A. W. Hull showed* that the device can be used to measure the ratio e/m of an electron. When a positive potential is applied to the anode electrons move in straight paths perpendicular to the axis. On applying the magnetic field the paths become curved, without, however, affecting the magnitude of the anode current, provided the electrons ultimately reach the anode. But as the magnetic field is gradually increased a critical value is reached at which the electrons just fail to reach the anode, passing tangentially to it and returning to the filament in a path similar to that of approach. This path can be shown to be a cardioid if the effect of the magnetic field on the distribution of space charge is neglected. If V denotes the potential-fall from anode to filament, H the critical magnetic field intensity, and R the internal radius of the anode, it can be shown that

$$e/m = 8V/H^2R^2$$

In the demonstration a diode in a bulb of the type used in the ordinary receiving valve is used, the anode being of copper. (This valve was supplied by the General Electric Research Laboratories, by courtesy of the Director, Mr. C. C. Paterson.) The valve is placed between the parallel faces of the pole-pieces of an electromagnet in series with battery, ammeter, carbon rheostat and switch. In the anode circuit of the valve is a shunted mirror galvanometer, the deflections of which are indicated by a disc of light moving over a scale. The value $V = 100$ volts was found suitable. R was 0·5 cm., and the critical fall of anode current was reached at $H = 130$ gausses.

The current through the electromagnet having been increased to the critical value, the switch is opened and the galvanometer spot allowed to regain its steady maximum deflection. On now once more closing the circuit of the electromagnet, no effect on the position of the spot of light is observed for an appreciable interval of time (some two or three seconds with the electromagnet used), after which the spot makes a sudden descent towards zero. The magnetron thus serves to show in a striking manner the finite time required for the electric current to build up in an inductive circuit to which a steady electromotive force is applied.

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* Physical Review (1921).

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